# Well P&A Technology Qualification Framework Guidance

Issue 1



DNV – SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT – 1864

☐ Witnessed ☑ Reviewed
And found to comply with:
TQ Framework Reviewed Only as per Scope and defined under Memo 10580532-TQF-MEM-001 Rev 0
Date: 06/10/2025
Sign: ZILPET

Astrimar
Reliability by Design
Engineered Solutions • Technology Qualification • Asset Integrity

Net Zero Technology Centre
Technology Driving Transition

**The framework is designed to promote effective collaboration, by establishing clear expectations rather than dictating rigid roles. The Operator should actively participate in the Technology Qualification process, working alongside the Technology Provider, and ultimately ensuring the mitigated risk of the new technology is acceptable prior to actual use.**





## Authors




**Dr. Caroline Roberts-Haritonov**
Managing Director, Astrimar



**Brian Willis**
Senior Engineer, Astrimar



**Heather Woods**
Project Engineer, Net Zero Technology Centre



**Lewis Harper**
Programme Manager, Net Zero Technology Centre


## Acknowledgements


In preparing and publishing this document, the Net Zero Technology Centre (NZTC) acknowledges the significant input from Astrimar.

Astrimar is an independent engineering consultancy specialising in reliability assurance and technical risk management. They help clients in the energy, utilities and water sectors deliver reliable, high-integrity systems through expert engineering design, analysis and qualification. Their team combines deep industry experience with a strong focus on best practice, supporting projects from concept through to operation. Their aim is to ensure dependable performance across complex engineered systems.

NZTC also acknowledges input from industry partners, including ConocoPhillips, Equinor, Harbour Energy, Havtil, the Health and Safety Executive (HSE), National Offshore Petroleum Safety and Environmental Management Authority, the North Sea Transition Authority (NSTA), OKEA, Offshore Petroleum Regulator for Environment and Decommissioning, Petrobras, Repsol and TotalEnergies.

Find out more here



**Disclaimer**
This document has been produced by Astrimar for NZTC for the specific purpose of developing a Technology Qualification Framework for Well P&A Technologies and is only suitable for use in this context. The document may not be used by any other party or for any other purpose without Astrimar's written permission.

While every effort has been made to ensure the accuracy of the information in this publication, NZTC, Astrimar, and the companies listed above accept no liability for any use of this publication or the guidance it sets out.

Copyright © 2025 Net Zero Technology Centre

# Abbreviations

| Acronym | Definition |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| API | American Petroleum Institute |
| CAP | Competent Authority Portal |
| CFD | Computational Fluid Dynamics |
| CO2 | Carbon Dioxide |
| DNV | Det Norske Veritas |
| EAC | Element Acceptance Criteria |
| ETA | Event Tree Analysis |
| FMECA | Failure modes, Effects and Criticality Analysis |
| FTA | Fault Tree Analysis |
| GRE | Glass Reinforced Epoxy |
| H2S | Hydrogen Sulphide |
| HAZID | Hazard Identification |
| HAZOP | Hazard and Operability Study |
| HIRA | Hazard Identification and Risk Assessment |
| HSE | Health and Safety Executive |
| ISO | International Organization for Standardization |
| MSAD | Minimum Safe Abandonment Depth |
| MTTF | Mean Time To Failure |
| NASA | National Aeronautics and Space Administration |
| NSTA | North Sea Transition Authority |
| NZTC | Net Zero Technology Centre |
| OEUK | Offshore Energies UK |
| OMAR | Offshore Major Accident Register |
| OPRED (EMT) | Offshore Petroleum Regulator for Environment and Decommissioning (Environmental Management Team) |
| P&A | Plug and Abandonment |
| PETS | Portal Environmental Tracking System |
| QA | Quality Assurance |
| QC | Quality Control |
| R&D | Research and Development |
| RACI | Responsible, Accountable, Consulted, Informed |
| RAM | Reliability, Availability Maintainability |
| RBD | Reliability Block Diagram |
| SCP | Surface Casing Pressure |
| TQ | Technology Qualification |
| TQP | Technology Qualification Process |
| TRL | Technology Readiness Level |
| UKCS | UK Continental Shelf |
| WBE | Well Barrier Element |
| WDSG | Wells Decommissioning Steering Group |
| WONS | Well Operations Notification System |



# Table of Contents


1 Introduction ..... 6
2 Outline of the Technology Qualification Framework ..... 7
3 The Technology Qualification Process Overview ..... 10
4 Preparing for Well Barrier Deployment ..... 12
5 Technology Qualification Framework Roles & Responsibilities ..... 14
6 Step 1: Candidate Technology Identification ..... 16
7 Step 2: Technology Specification against Requirements ..... 17
8 Step 3: Assessment of Technology Maturity and Qualification Gaps ..... 18
9 Step 4: Assessment of Failure Modes (FMECA) ..... 19
10 Step 5: Identification Qualification and Risk Mitigation Actions ..... 20
11 Step 6: Technology Qualification evidence and Deployment Checklist ..... 21
12 External References ..... 22
13 Framework Documents ..... 22
Appendix 1. Framework Alignment with Industry Regulations ..... 23
Appendix 1.1. United Kingdom Regulations ..... 23
Appendix 1.2. Norway Regulations ..... 25
Appendix 1.3. United Kingdom Guidelines ..... 29
Appendix 1.4. Norway Guidelines ..... 37
Appendix 2. Example EAC table for Alternative Barrier Materials ..... 40
Appendix 3. Claiming a Novel Well Barrier is “Proven” at TRL 9 ..... 42
Appendix 4. Deployment Checklist Guidance ..... 46
Appendix 4.1. Why a Deployment Checklist is recommended ..... 46
Appendix 4.2. Phases, sections and examples of checklist items ..... 46
Appendix 4.2.1. Planning and Preparation Phase ..... 46
Appendix 4.2.2. Deployment and Execution Phase ..... 48
Appendix 4.2.3. Qualification Status ..... 49
Appendix 4.2.4. Additional Technology Specific Checks ..... 50


# Table of Figures


Figure 1: Framework process – alignment with DNV RP A203 ..... 7
Figure 2: Technology Qualification Framework Process ..... 9
Figure 3: UKCS Well Decommissioning Regulation: Consents, Well Notifications & Permits ..... 14
Figure 4: RACI Chart ..... 15
Figure 5: Number of monitored wells required to claim a 3000 year life, based on Chi Squared Analysis ..... 42
Figure 6: Number of tests to demonstrate reliable well barrier installation, based on Binomial Distribution ..... 43
Figure 7: Graphical representation of number of rests to demonstrate reliable well barrier installation, based on Binomial Distribution ..... 44

# 1.
# Introduction

**The purpose of this Technology Qualification Framework is to streamline the acceptance process and facilitate the use of alternative materials for use in the permanent plugging & abandonment of oil and gas wells.**

Technology qualification is “the process of providing evidence that technology will function reliably within specified operational limits with an acceptable level of confidence.”[1]

Whenever technology is developed or modified it introduces a degree of uncertainty and risk in how it will perform. Technology qualification addresses all levels of technology testing and analysis undertaken to understand the risks and provide a level of assurance that the technology will function as required.

Testing and analysis activities help Technology Developers to understand the potential performance of new or modified technology along with the risks of technology development and deployment. Technology qualification is the overarching process that manages the evidence of technology performance and enables technology to be more readily adopted.

The Technology Qualification Framework Roadmap represents the qualification process adapted specifically for alternative well plugging materials and is based on common principles and processes from established and industry accepted Technology Qualification Processes.  The TQ Framework process is described in Section 2.

The technology qualification process presented within the Roadmap incorporates requirements from regulations and standards, and is developed to be bespoke to unique applications and challenges associated with the qualification of alternative well barrier technologies for well P&A. It has been developed with discussion /input from Operators, Technology Developers and Regulators, and illustrates the various roles and activities relevant to each party within the process.

The intent is that the standardised framework represented by the Roadmap and supporting framework documents, will be applicable across multiple Operators and regions and applicable to all material and barrier types.

The Roadmap, presented in Figure 2 will be accessible as an interactive tool, with links to relevant supporting documents, tools and templates.

The process to be followed, the types of activities and resourcing required will depend on the maturity of the technology and the technology risk. Early engagement with Regulators, as well as between Operators and Technology Developers, is encouraged to ensure all requirements and expectations are well understood and can be addressed.

It is recognised that well barrier technologies being addressed through the Framework will not always be first of a kind, and in which case, well and well architectures of subsequent deployments are likely to be similar to previous deployments for a specific technology.  However, any differences between deployments should also be carefully assessed against the original Requirements Proforma, to ensure any new risks or qualification gaps are identified and appropriately managed through the framework.

It should be noted that this Framework and supporting documentation has been developed to help facilitate the qualification and acceptance of new barrier technologies within the wider well decommissioning design. Therefore, this Framework is not intended to replace, but supplement the requirements of the regulations including activities that would be considered as standard for any well decommissioning design and execution (e.g. cement plugs). These standard activities would also need to be carried out to demonstrate adequate risk assessment and risk management of the full well decommissioning design and implementation.

This framework provides a structured guideline for achieving qualification by systematically evaluating all requirements for a defined application. The qualification of the selected technology for this application then involves the confirmation that it is fit for this intended purpose through a systematic, documented process of design review, analysis, and testing to demonstrate safety, reliability and performance, and that any risks are understood and managed. It’s important to understand that following this process is not intended to result in certification, which would be provided through an independent verification body on the basis of compliance with specific industry standards or requirements.

The framework is designed to promote effective collaboration, by establishing clear expectations rather than dictating rigid roles. The Operator should actively participate in the Technology Qualification process, working alongside the Technology Provider, and ultimately ensuring the mitigated risk of the new technology is acceptable prior to actual use.



# 2.
# Outline of the TQ Framework Process

The TQ Framework process is aligned to the DNV-RP-A203 Technology Qualification process as presented in Figure 1.

Technology qualification is the systematic process of demonstrating through the provision of evidence that a technology will function to the specified requirements and reliability and within its required operable limits.

The TQ Framework process is intentionally closely aligned to the DNV-RP-A203 Technology Qualification (2021) [1] recommended practice as well as the OEUK guideline on Use of Barrier Materials in Well Decommissioning (Issue 3 [2]. Other industry practices on Technology Qualification are also very much aligned including:

- API RP 17Q (2018): Technology Qualification [3]
- LR-GN-001 Guidance Notes for Technology Qualification, Lloyds Register (2022) [4]
- Bureau Veritas Guidance Note NI525 R01 (2020): Risk based qualification of new technology - methodological guidelines [5]

Each of these industry guidance documents follow similar steps on which the NZTC TQ Framework process 6 steps are based, as described below:

- **Step 1:** Candidate Technology Identification
- **Step 2:** Technology Specification against Requirements
- **Step 3:** Assessment of Technology Maturity and Qualification Gaps
- **Step 4:** Assessment of Failure Modes (FMECA)
- **Step 5:** Identification of Qualification and Risk Mitigation Actions
- **Step 6:** Technology Qualification Evidence and Deployment Checklist

**Framework Process - Alignment with A203**

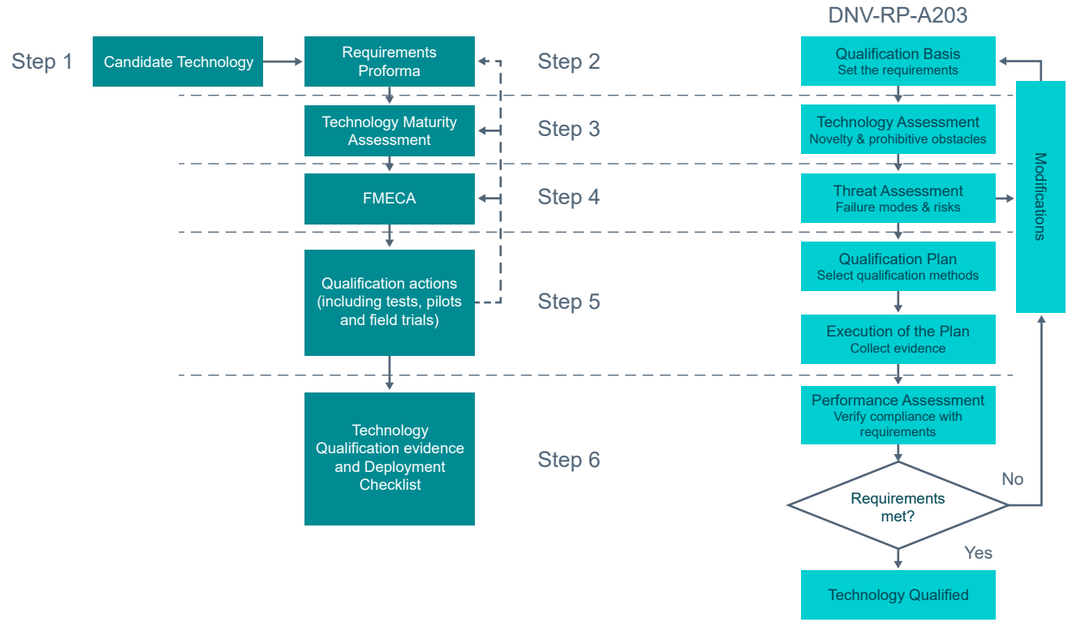



Figure 1: Framework process – alignment with DNV-RP-A203 [1]

## Step 1

### Candidate Technology Identification

Before a technology can be assessed for its suitability for use, it is essential to be clear what the technology being considered consists of. Any options within a technology specification need to be confirmed such that the identified technology is clearly defined and unambiguous.

## Step 2

### Technology Specification against Requirements

The definition of a qualification basis underpins each of the other TQ activities. This is recognised in all of the guidance documents as the initial step in defining technology goals and requirements. The technology specification against requirements, step is intended to provide a common approach to defining technology requirements for a specific application and the identified technology's ability to meet those requirements. Requirements should be defined quantitatively as far as possible for the application under consideration.

The process to prepare the deployment checklist should be initiated in parallel to the requirements specification. The deployment requirements should be aligned to, input to and reflect the requirements defined in the Requirements Proforma for the selected technology and application. See also Section 4 and APPENDIX 4.

## Step 3

### Assessment of Technology Maturity and Qualification Gaps

This step is recognised by all key TQ guidance documents. However, they differ significantly in how the technology assessment and maturity assessment activities are carried out, the generic TRL ladder (levels 1 – 9 widely adopted across many industries are very high level in their definition and relate to technologies that can follow a traditional concept to prototype to deployment testing programme. Because novel barriers are not fully formed (and material properties developed until they are deployed in the well, the route to achieving each TRL has to be adapted. The development of the NZTC TQ Framework has involved a significant collaborative effort to define what each TRL means for novel well barriers and how they can be achieved.

## Step 4

### Assessment of Failure Modes (FMECA)

A rigorous threat assessment (often undertaken as a failure mode, effects and criticality assessment, FMECA) is considered an essential step in the Qualification process to define an effective technology plan. Many guidance documents recommend that all technology qualification activities are traceable back to the FMECA.

It is not clear how effectively this is done as part of typical TQ practice as there is relatively limited guidance on how FMECA should be performed as part of a technology qualification process. There is even less guidance on how this should be applied to novel well barriers to address the required functions through the critical life cycle stages of installation (to achieve required material properties and geometries for a permanent seal), verification and validation (to confirm the requirements of a permanent well barrier are met), and long-term integrity (to ensure well barrier integrity is maintained in perpetuity). The NZTC TQ Framework therefore provides a guided template to ensure that the FMECA is carried out in a manner to address well barrier specific failure mode risks and support effective qualification across all life cycle stages to achieve long term barrier assurance.

## Step 5

### Identification Qualification and Risk Mitigation Actions

The qualification plan is at the heart of the TQP and is a key output from the earlier steps. All of the industry TQ guidance documents recommend the creation of a qualification plan. The key output of the Assessment of Failure Modes (FMECA) is an identification of qualification actions which may include actions like physical testing of materials and components, analysis and simulation and process development and documentation to name a few. The qualification actions identified through the FMECA provide the fundamental input to the creation of the qualification plan. This ensures traceability between the qualification test plan, the application-specific FMECA and its arising actions, and the technology qualification basis/requirements defined at the start of the process.

## Step 6

### Technology Qualification Evidence and Deployment Checklist

All of the industry TQ guidance documents recognise the need to assess or evaluate the results of qualification activities against requirements and ensure that all mitigations have been put in place. Typically, this is documented in a Technology Qualification (TQ) report, which is a formal document that provides evidence that a new technology is fit for service in a specific application. Its primary purpose is to present and document, in a complete and traceable manner, a review of the qualification evidence which demonstrates that the risks associated with deploying novel technology are acceptable. The report describes the technology and its intended use, identifies all associated risks and uncertainties, and details the qualification activities—such as testing and analysis—that were performed to address them. By presenting all the supporting evidence and data, the report ultimately concludes that the technology is ready for deployment, often including a final statement on its performance capabilities, reliability and any operational limitations.

The Operator needs to be able to demonstrate to the Regulator that they have gained sufficient confidence from the Technology qualification activities and remaining risk mitigations that any residual uncertainty and risks have be reduced to as low as reasonably practicable. The deployment checklist developed within the NZTC TQ Framework is a key tool for ensuring all relevant steps and actions have been fully implemented.

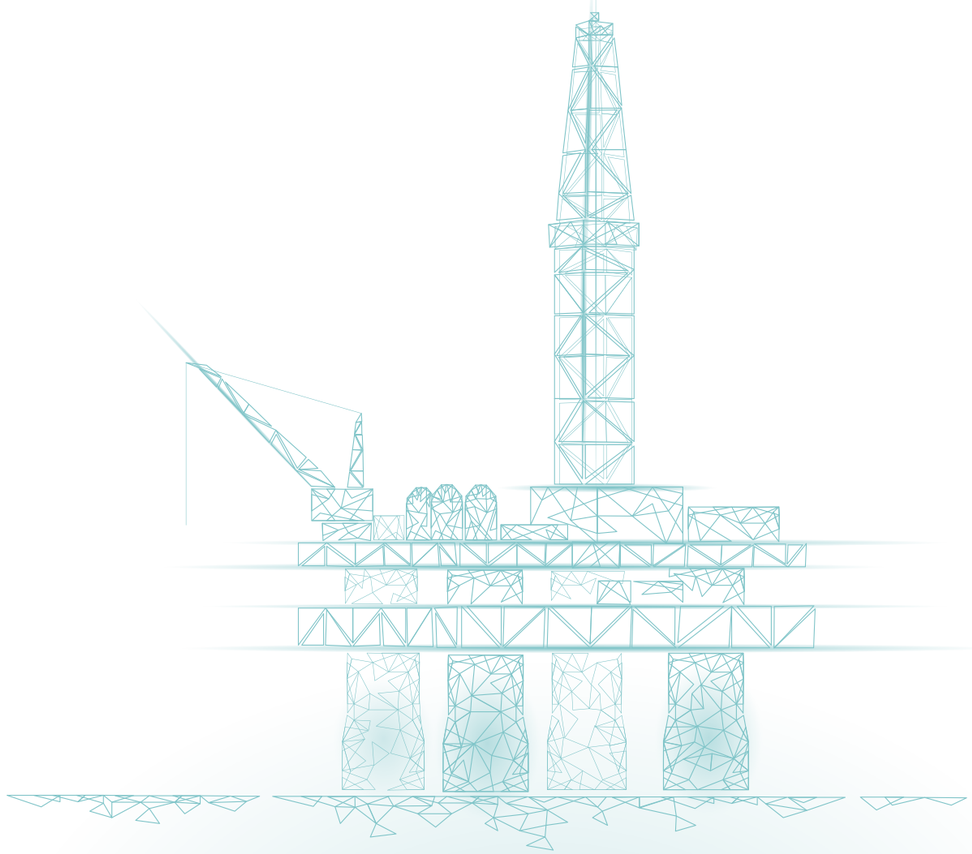




## 3.
# The Technology Qualification Framework: Process Overview

The Technology Qualification Framework Roadmap is presented in Figure 2. It shows the TQ Framework process, from left to right at the top of the image and coloured coded “swim lanes” of associated activities for the Operator and Technology Provider running in parallel to the overall framework process showing the different organisation roles at each stage. Additional potential support/interaction with NZTC, Regulators and TQ consultants are also shown.

This different organisation roles (and supporting tools and worksheets) are described for each step in the Framework process in the following sections of this document.



### Process overview

| | | | | | | |
|---|---|---|---|---|---|---|
| Framework Process | Candidate technology selected for Framework | Requirements Proforma | Technology Maturity Assessment | FMECA | Qualification actions (including tests, pilots and field trials) | Technology Qualification evidence and Deployment Checklist |
| OPERATOR | Operator identifies well | Defines well specific barrier technology requirements | Assesses the technology maturity and required maturity for the application | Supports the technology risk assessment and confirms residual risks | Provides financial and technical support including pilot wells | Reviews evidence, updates risk assessment, approves completed deployment checklist |
| TECHNOLOGY PROVIDER | Provides well barrier technology/ies | Details well barrier technology/ies capabilities | Demonstrates technology readiness | Undertakes technology risk assessment (FMECA) and identifies qualification actions | Plans and performs trials, tests, analysis and simulations, and documents processes | Documents evidence and completes deployment checklist to demonstrate requirements met |
| NZTC | Calls for well barrier technology/ies | Aligns Operator requirements with Technology Providers | Provides tools to facilitate Technology specifications and readiness assessment | Encourages use of good practice to reduce risk of new technology | Facilitates access to test facilities, trials and specialists | Engages with regulators and organisations to seek consent for technology use |
| Other potential consultancy support (E.g Astrimar) | Supports identification of potential technologies | Supports operator definition of requirements / technology definition of capabilities | Provides support / review of technology maturity assessment | Provides facilitation / review of application FMECA | Provides support / review of qualification test plans and /or results | Provides support / review of documented evidence |
| Regulators | Encourage opportunities for new technologies | Confer expectations on suitability and use of new technologies | Informed of technology readiness for a specific applications, on request | Provided details of identified risks | Provided assurance of risk mitigation | Provided evidence of completed deployment checks and completion of qualification actions |

Figure 2: Technology Qualification Framework Process

# 4.
# Preparing for Well Barrier Deployment

As part of preparing for well barrier deployment, a Deployment Checklist should be prepared as an operational tool to support the verification and installation of alternative well barrier materials. Its purpose is to ensure the material and barrier will perform as intended, in line with established qualification assurance measures.

The preparation of the Deployment Checklist should ideally begin alongside the preparation of the Requirements Proforma. It is important that any requirements identified in the deployment checklist are consistent with the requirements defined within the requirements proforma, FMECA and Technology Maturity assessment and vice versa. The eventual signing off of the checklist should close the loop on the technology requirements and the generation of evidence to show that the requirements have been met by the technology, its qualification and risk mitigation.  If any differences are introduced via the deployment checklist, this will require that updates and re-assessments of the FMECA and Technology Maturity are undertaken – with associated actions updated too.

The checklist included as part of Step 6 of the Technology Qualification Framework is influenced by the OEUK Guidelines for the Use of Barrier Materials in Well Decommissioning [2] and aligned with the Well Barrier EAC tables as required by NORSOK D-010 [10]. It is designed to meet the expectations of both.

The checklist provided as part of this Framework [19], presents a structured set of example items to guide the creation of tailored deployment checklists for specific technologies and applications. Actual checklist requirements will vary depending on well characteristics, regulatory frameworks, and the selected materials or technologies involved.

The provided Deployment Checklist template is initially broken down into the following operational phases Planning and Preparation; Deployment and Execution; Post-deployment and Reporting; and Qualification Status, and these are further split into sections against which example checklist items have been defined. The expectations of each of these sections are described in APPENDIX 4, including example items from the checklist template.  These should be carefully considered through the process of defining the technology application requirements and through the implementation of qualification and risk assurance for deployment readiness.



# 5.
# Technology Qualification Framework Roles & Responsibilities

The implementation of the Technology Qualification Framework requires input, review and buy-in from a number of different organisations. Of key importance is the use of the framework to communicate with the Regulator(s) the extent of the qualification evidence gained and the assurance that the well barrier technology is fit for purpose within the wider well decommissioning design, and all residual risks are as low as reasonably practicable. The NZTC technology framework has been explicitly developed to support alignment to the relevant industry regulations. This alignment is presented in APPENDIX 1.

The role(s) of the Regulators (in the UKCS) in reviewing and consenting to the well barrier claims are presented in Figure 3, taken from the NSTA and Wells Decommissioning Steering Group (WDSG) [6].

A blank RACI chart is shown in Figure 4, and reflects the need to undertake a wider assessment of the roles and responsibilities for the range of organisations involved in the development, qualification, consent, installation and operation of the permanent well barrier using novel barrier materials. This should be completed by all Stakeholders. An editable version of this chart alongside general expectations of roles, is available in the RACI Chart Template workbook [18].

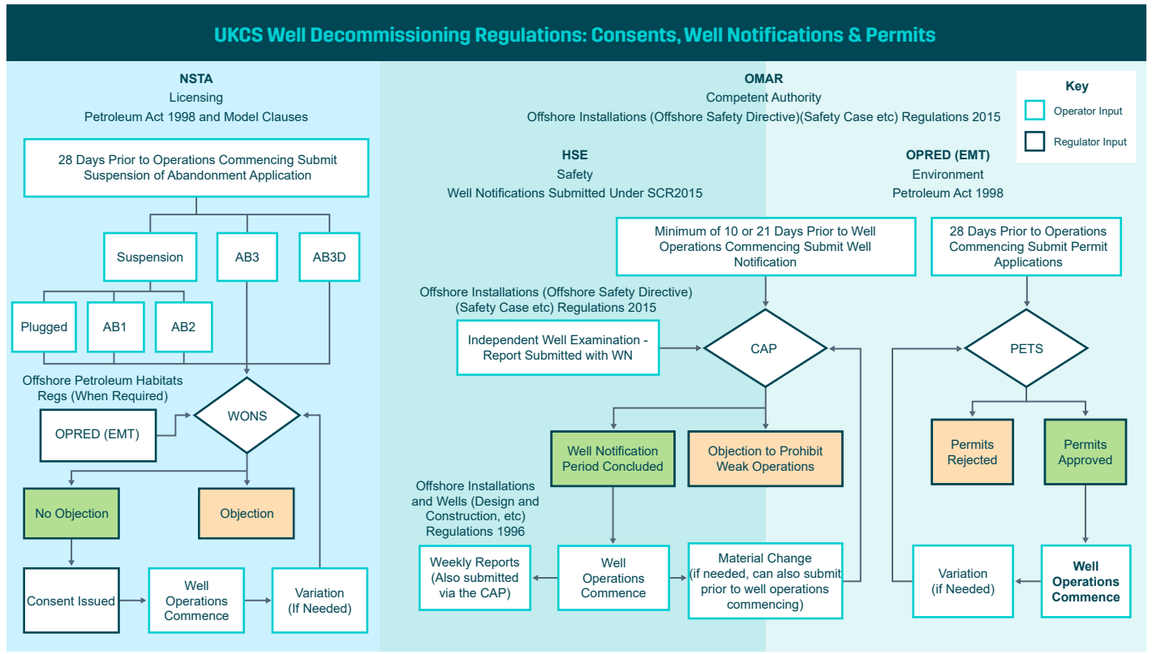



Figure 3: UKCS Well Decommissioning Regulation: Consents, Well Notifications & Permits [6]

| Activity | Technology Provider | Operator | NZTC | Assurance/ Certification | NSTA | OPRED | HSE |
|---|---|---|---|---|---|---|---|
| **Step 1** - Candidate Technology Identification | | | | | | | |
| **Step 2** - Technology Specification against Requirements | | | | | | | |
| **Step 3** - Assessment of Technology Maturity and Qualification Gaps | | | | | | | |
| **Step 4** - Assessment of Failure Modes (FMECA) | | | | | | | |
| **Step 5** - Identification Qualification and Risk Mitigation Actions | | | | | | | |
| **Step 6** - Technology Qualification evidence and Deployment Checklist | | | | | | | |

Figure 4: RACI Chart (Intentionally left blank and to be agreed by Stakeholders)

**Key:**

R - Responsible (carries out the work to complete the task)

A - Accountable (final approval of the deliverable)

C - Consulted (provides input)

I - Informed (information provided to rather than being required from)

# 6.
# Step 1: Candidate Technology Identification

| Organisation | Activity | Description |
|---|---|---|
| Operator | Operator identifies well | The process initiates with the Operator identifying a well, or series of wells for which the use of alternative barrier technology/ies is of interest. Often the application of alternative barrier technology(ies) may be driven by the candidate well having specific (non-standard requirements). These may include:<br><br>• Insufficient height below MSAD to enable a “standard” cement barrier<br>• Wellbore access constraints<br>• Annulus barrier integrity concerns<br>• Limitations on rig accessibility<br>• Remaining cables / tooling downhole<br>• Rig, time and cost constraints<br><br>As barrier technologies become proven, it is anticipated that they will be used more widely on both standard and nonstandard wells. |
| Technology Provider | Provides well barrier technology/ies | The Technology Provider needs to be able to communicate the capability and maturity of their technology for use in a range of applications. The Technology Provider benefits from an understanding of actual or potential well P&A applications to help them determine the potential for their technology to meet the upcoming need, and to identify gaps that their technology may need to evolve to address. Proactive engagement with Operators and / or NZTC at this stage can help to accelerate recognition and adoption of potential solutions. |
| NZTC (potential support) | Calls for well barrier technology/ies | In discussions with Operators and Regulators, NZTC has the opportunity to look forward at future industry needs and communicate these in a generic form to the wider developer community to help shape innovation activity and open the door to as yet unknown technology solutions. |
| Regulators | Encourages opportunities for new technologies | The Regulators are open to any technologies or techniques that have the potential to deliver efficient, effective and safe well decommissioning with respect to the environment. |
| Astrimar (or consultant) potential support | Supports identification of potential technologies | With an independent position, Astrimar or similar consultant can provide market research of potential technologies and developers that may be able to meet specific future needs. |
| Tool | Requirements Proforma [15] | While no specific tool is needed for this step in the process. The Requirements proforma could be initiated to start to capture relevant information. |



# 7.
# Step 2: Technology Specification against Requirements

| Organisation | Activity | Description |
|---|---|---|
| Operator | Defines well specific barrier technology requirements | The Operator should define the requirements to be met by the new technology to safely and economically achieve the required outcome. These requirements should consider all life-cycle stages from planning and preparation, installation, verification, monitoring (if applicable) to through-life and encompass technical, operational and procedural considerations.<br><br>For certain requirements, consideration should be given to conditions that may change over time.<br><br>Where possible, requirements should be defined in a way that covers as many wells within a given campaign as possible, minimising the need for well-specific or individualised requirements. |
| Technology Provider | Details well barrier technology/ies capabilities | The current capabilities of the technology should be specified and compared to the Operator’s application requirements. Any misalignment should be highlighted for further discussion.<br><br>It is recommended to include references to previous use or qualification of parts, components, and sub-systems of the technology where relevant.<br><br>Where Operator requirements are incomplete or unavailable, the Technology Provider should define the technology specification and capabilities by completing the Requirements Proforma. |
| NZTC (potential support) | Aligns Operator requirements with Technology Providers | Although not a requirement, it may be beneficial to involve NZTC, as they can gather information across the broader industry for potential upcoming requirements and applications for the technology.<br><br>By facilitating discussions between the new Technology Providers and potential end users they can raise awareness of the new technology and its capabilities. |
| Regulators | Confer expectations on suitability and use of new technologies | Although not a requirement, it may be beneficial to involve the Regulators, as they can discuss their expectations for the suitability and use of new technologies for specific well applications, and to encourage a risk managed approach and technology qualification process. |
| Astrimar (or consultant) potential support | Supports operator definition of requirements / technology definition of capabilities | Although not a requirement, it may be beneficial to involve Astrimar, or similar consultant, to provide guidance to ensure the generation of accurate requirements and specifications for the new technology. |
| Tool | Requirements Proforma [15]<br>Deployment Checklist [19] | The Requirements Proforma should be used to both present the technology capability for the required application and the required application for the potential technology. The deployment checklist, developed based on the regulations and requirements should also feed back into the requirements proforma and be developed in parallel. |

## 8.
# Step 3: Assessment of Technology Maturity and Qualification Gaps

| Organisation | Activity | Description |
|---|---|---|
| Operator | Assesses the technology maturity and required maturity for the application | The Operator should actively participate in the TRL assessment process by reviewing the Technology Provider's assessment if available. They should communicate the required TRL for the specific application, and their understanding and expectation of qualification activities for each TRL.<br><br>Where qualification gaps are identified, the Operator should ensure the associated technology risks are clearly defined, along with the necessary activities to raise the TRL. This information is crucial for accurately estimating the required time, cost, and effort. |
| Technology Provider | Demonstrates technology readiness | The Technology Provider should carry out a TRL assessment for their new technology relevant to the intended application, using the TRL assessment tool, which outlines five specific criteria and activities for each TRL level.<br><br>Populating the TRL assessment tool enables the identification of the TRL as it progresses through development, qualification and implementation stages. This process allows the Technology Developer to communicate the deployment readiness to Operators and stakeholders and identify any development or qualification gaps. |
| NZTC (potential support) | Provides tools to facilitate technology specification and readiness assessment | Although not a requirement, it may be beneficial to involve NZTC, as they have the opportunity to work with Operators, Regulators and stakeholders to establish TRL gates for progression of new technology development and implementation, as required. |
| Regulators | Informed of technology readiness for a specific application, on request. | The Regulators should be provided details, on request, of the technology readiness (i.e. TRL level), prior to deployment of the selected technology for the specified application(s). Any identified TQ gaps and arising residual risks associated may be discussed. |
| Astrimar (or consultant) potential support | Provides support / review of technology maturity assessment | Astrimar, or similar consultant, is available to provide independent evaluation of the TRL assessment carried out to ensure that it is completed accurately for the context of the application and in line with established generic industry guidance as well as the novel well barrier specific guidance developed by Astrimar and contained in the NZTC framework Technology Maturity Assessment worksheet. |
| Tool | Technology Maturity Assessment [16]<br><br>Sub-system/Component TRL Assessment: FMECA Template [17] | The Technology Maturity Assessment worksheet has been developed to enable assessment of Technology Readiness based on the standard 1-9 TRL ladder. Definitions adapted specifically for novel well barrier technologies have been developed and detailed criteria defined, to enable a justifiable and auditable assessment of technology readiness to be undertaken specific to the defined application.<br><br>If a sub-system or component level TRL assessment is required, it may be completed using the FMECA worksheet by utilising the TRL-specific columns, on a line-by-line basis. |

Note:
While every effort has been made to objectively identify and define activities against specific technology readiness levels, this tool is ultimately a qualitative assessment technique and may be open to subjectivity and interpretation. It is therefore recommended that the Technology Developer and Operator review and agree the claimed TRL and development gaps.



## 9.
# Step 4: Assessment of Failure Modes (FMECA)

| Organisation | Activity | Description |
|---|---|---|
| Operator | Supports the technology risk assessment and confirms residual risks | The Operator should participate in the FMECA due to their specific knowledge of the application, which may also include operational risks that impact probability of success. The Operator should review and provide feedback on the FMECA compiled by new Technology Provider to confirm all known potential failure modes are included for the expected application and risk mitigation steps meet expectations. It is recommended that this is conducted as a workshop with Operator representatives included. |
| Technology Provider | Undertakes technology risk assessment (FMECA) and identifies qualification actions | New Technology Provider is to carry out the FMECA, in the context of the expected application, in order to systematically evaluate all potential modes of failure, that could occur when using the new technology.<br><br>Mitigations for potential failure modes will also be included in the FMECA to establish risk reduction steps prior to technology implementation. These can include, but are not limited to:<br><br>• Design improvements<br>• Analysis<br>• Testing<br>• Procedural control |
| NZTC (potential support) | Encourages use of good practice to reduce risk of new technology | NZTC should encourage the use of FMECA as a tool for the Operator to carry out risk management.<br><br>The use of FMECA should also be promoted to the new Technology Provider as it is an extremely valuable tool for enabling the new Technology Provider to demonstrate structured and recordable risk assurance for the Operator. |
| Regulators | Provided details of identified risks | The Regulators should be provided details, on request, of the failure mode identification and risk management process associated with the potential deployment of the selected technology for the specified application(s). |
| Astrimar (or consultant) potential support | Provides facilitation / review of application FMECA | Although not a requirement, it may be beneficial to involve Astrimar, or similar consultant, as they can create a FMECA template, prepopulate the workbook, and facilitate workshops for both the new Technology Provider and stakeholders in order to ensure accurate population of the template to cover all foreseen failure modes during use of the new technology. |
| Tool | FMECA Template [17]<br><br>Deployment Checklist [19] | The FMECA template provides a consistent basis for assessing the potential failure modes, effects and criticalities associated with the installation, verification and long-term integrity performance of the well barrier technology. With a standardised menu of potential failure modes and mechanisms addressing both the installation equipment and process, as well as the barrier technology itself, it provides a consistent level of rigour to each potential technology. Actions arising should, where appropriate be added to the Deployment Checklist. |

Notes:
Generic likelihood, consequence and risk acceptance criteria from DNV-RP-A203 are included in the FMECA template. If an Operator's risk matrix and acceptance criteria significantly differ or are not transferable, or that the included criteria will not be accepted, it is recommended that the Operator provide their own risk matrix and acceptance criteria.

## 10.
# Step 5: Identification of Qualification and Risk Mitigation Actions

| Organisation | Activity | Description |
|---|---|---|
| Operator | Provides financial and technical support including pilot wells | To advance the maturity of the technology, the Operator should provide both technical and financial support to the Technology Provider, and guidance to ensure its suitability for the Operator's specific application.<br><br>Support may include targeted testing or implementing risk mitigation actions previously identified as relevant to the Operator's planned use.<br><br>In addition to supplying specific well information, the Operator should identify and evaluate the availability of a suitable pilot well for the initial field deployment of the technology. |
| Technology Provider | Plans and performs trials, tests, analysis and simulations, and documents processes | Any remaining trials, testing, and analysis are to be conducted to address outstanding qualification or risk mitigation actions, in order to demonstrate that the new technology can reliably meet the requirements. These may include, but are not limited to:<br><br>- Finite Element Analysis (FEA)<br>- Computational Fluid Dynamics (CFD)<br>- Calculations<br>- Physical testing (including, material testing, function testing, lab scale, full scale, yard or field trials)<br>- Reliability (e.g. RAM, FTA etc) and consequence (e.g. Environmental impact, Leak models, Gas plume, Oil spill etc) analysis<br>- Procedural definition |
| NZTC (potential support) | Facilitates access to test facilities, trials and specialists | Although not a requirement, it may be beneficial to involve NZTC, as they have the opportunity to support the Operator and Technology Provider in sharing information with Regulators, stakeholders, and the wider industry regarding the testing and qualification steps being undertaken. This collaboration helps ensure that the technology is effectively mitigating potential risks, including commercial risks, associated with its implementation.<br><br>NZTC can also facilitate connections between new Technology Providers and facilities available for testing /trials. |
| Regulators | Provided assurance of risk mitigation | The Regulators should be provided assurance, on request, of appropriate qualification or other risk mitigation actions associated with the potential deployment of the selected technology for the specified application(s). |
| Astrimar (or consultant) potential support | Provides support / review of qualification test plans and/or results | Although not a requirement, it may be beneficial to involve Astrimar, or similar consultant, as they are able to support throughout the qualification process to maximise the effectiveness of the testing being carried out, ensuring the identified risks are evaluated/demonstrated and valuable evidence is collated through the testing. In addition, independent review and witnessing of qualification test procedures and/or results can be offered for an independent verification body as part of a certification or compliance process. |
| Tool | Completed FMECA Template [17] Deployment Checklist [19] | The completed FMECA provides a rigorous basis for identifying, and signposting to, existing qualification evidence as well as further qualification activities (testing, analysis, pilots & field trials) and risk mitigation actions (procedural controls, training, monitoring, limitations on use), to ensure that the risks associated with deployment of the technology in the selected application is appropriately managed. This should form the basis of defining the required test program. Additional actions may be captured in the Deployment Checklist. |



## 11.
# Step 6: Technology Qualification evidence and Deployment Checklist

| Organisation | Activity | Description |
|---|---|---|
| Operator | Reviews evidence, updates risk assessment, approve completed deployment checklist and ensure engagement with Regulators | The Operator should thoroughly review all provided documented evidence and verify the mitigated risk assessment within the FMECA is ALARP, and confirm the final TRL assessment.<br><br>The intent of the deployment checklist is to support the verification and installation of alternative well barrier materials such that it will perform as intended. It should include all risk mitigations and procedures identified within the FMECA and should be executed for each deployment. The checklist should be updated to reflect any requirements or risk mitigations specific for the well- or campaign-related requirements.<br><br>A completed FMECA with all qualification and risk mitigation actions closed out, a deployment checklist and summary report, will provide valuable evidence when consent is sought from the relevant Regulators. |
| Technology Provider | Documents evidence and completes deployment checklist to demonstrate requirements met | The technology qualification report (as outlined in Section 2 Step 6) should be written to summarise the findings to Operators and stakeholders, providing the necessary assurance that all requirements are fully met with identified qualification actions completed. This may include summaries or sign-posting to the requirements proforma, technology maturity assessment, FMECA, qualifications actions and documented evidence, and any outstanding gaps or actions.<br><br>Technology Developer should also complete the deployment checklist in preparation for any deployment, including the list of checks required to support verification of the installed well barrier. |
| NZTC (potential support) | Is able to engage with Regulators / Operators to facilitate consent for technology use on behalf of the operator | Although not a requirement, it may be beneficial to involve NZTC, as they may facilitate discussions between the Operator and Regulators enabling the Operator to share collated evidence with Regulators, other Operators, and stakeholders to support application for consent for deployment of the new technology. |
| Regulators | Provided evidence of completed deployment checks and completion of qualification actions | The Regulators should be provided evidence, on request, of the completed qualification assurance; that residual risk and risk uncertainty are as low as practicable; and of a deployment checklist associated with the deployment of the selected technology for the specified application(s). |
| Astrimar (or consultant) potential support | Provides support / review of documented evidence | Although not a requirement, it may be beneficial to involve Astrimar, or similar consultant, as they can provide review services for the TRL assurance evidence and the deployment checklist. This would allow for an independent review of the documentation prior to submission to Regulators and consent for technology deployment. |
| Tool | Deployment Checklist [19],<br><br>Technology Qualification Report | In addition to the technology qualification report, the purpose of the deployment checklist is to support the Technology Developer and Operator in confirming that all risk mitigations, procedures and checks are in place, appropriately managed and communicated to all relevant parties during the technology deployment, supporting the verification of the installed well barrier against relevant regulations. |

# 12.
# External References


1. DNV-RP-A203, Technology qualification – edition Sep, 2019 (amended Sep, 2021)
2. OEUK, Use of Barrier Materials in Well Decommissioning Guidelines, Issue 3, 2022
3. API RP 17Q (2018): Technology Qualification
4. LR-GN-001 Guidance Notes for Technology Qualification, Lloyds Register (2022):
5. Bureau Veritas Guidance Note NI525 R01 (2020): Risk based qualification of new technology - methodological guidelines
6. NSTA and Wells Decommissioning Steering Group (WDSG), UKCS Well Decommissioning Regulation: Consents, Well Notifications & Permits, https://www.nstauthority.co.uk/media/3w2dnkes/020924-final-ukcs-welldecommissioning-regulation-v3.pdf
7. NASA - Technology Readiness Assessment – Best Practice Guide [SP-20205003605]
8. GOV - The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996, Part IV (1996)
9. Havtil - The facilities regulations and guidelines (amended December 2023), https://www.havtil.no/en/regulations/all-acts/?forskrift=634
10. Norsok – D 010, Well integrity in drilling and well operations, 2021
11. OEUK, Well Decommissioning Guidelines, Issue 7, 2022
12. Havtil - The management regulations and guidelines (amended December 2023), https://www.havtil.no/en/regulations/all-acts/?forskrift=611
13. Norsok – Z 013, Risk and emergency preparedness assessment, 2024
14. Oil & Gas Uk - Guidelines on Qualification of Materials for Abandonment of Wells Issue 2, 2015


# 13.
# Framework Documents

15. Requirements Proforma Template [AST-NZTC-01-TN-001 Rev D]
16. High Level Well Barrier TRL Assessment [AST-NZTC-01-TN-002 Rev D]
17. FMECA Template [AST-NZTC-01-TN-008 Rev C]
18. RACI Chart Template [AST-NZTC-01-TN-15 Rev A]
19. Deployment Checklist [AST-NZTC-01-PD-016 Rev A]



# Appendix 1.
# Framework Alignment with Industry Regulations

Most oil and gas producing regions across the world, have regulations in place which govern the responsibilities of well owners and the expectations for how wells should be designed and managed, including for the eventual permanent plugging and abandoning of wells. Further to this, there may be region specific industry standards and guidelines which well owners should adhere to, in order to satisfy that the expectations of the regulations are met.

The regulations of the U.K and Norway, are assessed against the technology qualification framework to determine how each of the requirements should be met.

## Appendix 1.1.
## United Kingdom Regulations

The following regulations are expected to be applicable in the United Kingdom, The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996, Part IV (GOV, 1996).

### General duty (GOV, 1996)

**Regulation 13.**

"(1) The well-operator shall ensure that a well is so designed, modified, commissioned, constructed, equipped, operated, maintained, suspended and abandoned that—

(a) so far as is reasonably practicable, there can be no unplanned escape of fluids from the well;

and

(b) risks to the health and safety of persons from it or anything in it, or in strata to which it is connected, are as low as is reasonably practicable.

(2) The provisions of regulations 14 to 19 and 21 are without prejudice to the generality of the requirements of paragraph (1) save that, where regulation 17(2) places a duty on the duty holder for an installation, the well-operator is not under the same duty."

**Interpretation**

The well should be abandoned such that there is no leak from the well, so far as is reasonably practical (i.e. ALARP) i.e. residual risks are acceptable.

The ALARP principle implies that the risks should be as low as practical, as long as the cost and effort to reduce the risk are not disproportionate to the risk reduction achieved.

Note that no lifetime is prescribed, therefore it can be assumed that this regulation applies in perpetuity.

**Framework Demonstration**

For a novel well barrier technology and well abandonment design, it is necessary to demonstrate that risks associated with the technology are ALARP. This will be assessed by a FMECA, and, if required a Quantitative Risk/ALARP Assessment of the well barrier envelope and abandonment design on a case-by-case basis. Qualification actions and risk mitigations arising from the FMECA assessed failure modes and mechanisms will support the appropriate management of risk.

### Design with a view to suspension and abandonment (GOV, 1996)

**Regulation 15.**

“The well-operator shall ensure that a well is so designed and constructed that, so far as is reasonably practicable—

(a) it can be suspended or abandoned in a safe manner; and

(b) after its suspension or abandonment there can be no unplanned escape of fluids from it or from the reservoir to which it led.”

**Interpretation**

Well barrier elements which are in place from the time the well was constructed are suitable for the permanent abandonment of the well and will not result a loss of containment.

Wells should be designed and constructed in such a way that they can be abandoned safely, and with no leak from the well.

**Framework Demonstration**

The assessment (and qualification) of the overall well barrier envelope is considered in the context of the alternative well barrier material. Failure modes and mechanisms are assessed both for the alternative barrier material and the existing well barrier elements with which it interfaces.

### Materials (GOV, 1996)

**Regulation 16.**

“The well-operator shall ensure that every part of a well is composed of material which is suitable for achieving the purposes described in regulation 13(1).”

**Interpretation**

Materials are qualified and proven for the purpose of permanent abandonment.

**Framework Demonstration**

Downhole conditions, performance and life requirements are identified within the Requirements Proforma. Qualification of material and well barrier will be determined using FMECA against the specified requirements. Will need to demonstrate that the Alternative Well Barrier Material achieves a TRL 8 for the application.

### Co-operation (GOV, 1996)

**Regulation 20.**

“Every person who is or is to be concerned (in whatever capacity) in an operation in relation to a well (including the drilling of a well) shall co-operate with the well-operator so far as is necessary to enable him to discharge his duties under regulations 13(1) and 17.”

**Interpretation**

Well barrier Technology Provider and other people supporting the deployment of alternative well barrier materials shall co-operate with the well-operator in meeting their duties.

**Framework Demonstration**

All support and evidence shall be made available to the well-operator to demonstrate that the alternative well barrier is qualified for the application – Demonstrated by completion of Requirements Proforma, TRL Maturity Assessment, FMECA and the provision of qualification evidence.



## Appendix 1.2.
## Norway Regulations

In Norway the following regulations are expected to be relevant and applicable for the qualification of new well barrier materials and elements.

### Norwegian regulatory regime – See-to-it duty (Havtil, 2024)

**Regulation**

“The operator has a particular responsibility for ensuring that activities are conducted overall in a prudent manner and in accordance with the regulations. This involves seeing to it that everyone complies with the requirements in the HSE regulations. The “see-to-it” duty is a general overarching obligation in addition to each company’s duty to comply with the regulations.”

**Interpretation**

The “see-to-it” duty is a fundamental principle in the Norwegian regulatory regime, placing the ultimate responsibility for overall HSE performance squarely on the Operator. This goes beyond simply complying with regulations themselves; the Operator must also actively ensure that all parties involved in the activity—including contractors, subcontractors, and suppliers—also follow all relevant HSE regulations. This is an overarching, supervisory obligation that exists in addition to the duty of each individual company to comply with the rules. Essentially, the Operator acts as the ultimate guarantor of safety and prudence for the entire operation.

**Framework Demonstration**

The Operator’s “see-to-it” duty is woven into the structure of the framework, ensuring active oversight and involvement throughout the technology qualification process. The framework also explicitly defines the roles and responsibilities of both the Operator and the Technology Providers which ensures the Operator is not a passive recipient of information but an active participant with an overarching supervisory and acceptance role.

### Framework regulation - §23 General Requirements (Havtil, 2011)

**Regulation**

“The responsible party shall prepare and retain material and information necessary to ensure and document that the activities are planned and carried out in a prudent manner. The responsible party shall ensure that documentation demonstrating compliance with requirements stipulated in or pursuant to these regulations, can be provided. The responsible party shall establish criteria for what constitutes necessary documentation. The extent of the documentation shall be adapted to the nature of the enterprise and the activities carried out. Such material and information as mentioned in the first subsection shall be available in Norway free of charge to the authorities”

**Interpretation**

The responsible party is required to:

- Create and keep records and information that demonstrate activities are planned and executed safely and prudently.
- Ensure that this documentation proves compliance with all relevant regulations.
- Define clear criteria for what constitutes essential documentation.
- Tailor the scope and amount of documentation to the specific nature and activities of the company.
- Make all required documentation readily available to Norwegian authorities at no cost.

**Framework Demonstration**

The framework itself acts as a structured system for documenting technology qualification, directly addressing the requirements. The Requirements Proforma, FMECA, Deployment Checklist, Technology Maturity Assessment and Technology Qualification Report collectively form the complete body of necessary documentation. These documents are designed to ensure and prove that activities are planned and carried out in a prudent manner by providing a transparent and auditable trail of all qualification steps.

## Framework regulation - §23 General Requirements (Havtil, 2011)

**Guideline**

“The section clarifies a general documentation obligation for the responsible party and applies within the entire health, safety and environment area.”

“The provision does not say anything directly regarding where or how materials and information shall be stored, or who specifically shall do this. For example, it can be stored with a contractor, abroad, in an electronic format or in some other manner. The requirement is for materials and information to be made available to the supervisory authorities within a reasonable time. What constitutes a reasonable time, will for example depend on the importance of the materials or information and the matter.

The responsible party itself shall evaluate the need for documentation, and the provision facilitates utilising available documents and documentation systems at suppliers and sub-suppliers.”

**Interpretation**

This guideline explains that the responsible party must maintain a general documentation system for all health, safety, and environment (HSE) matters. The regulation gives the responsible party flexibility in how and where to store this documentation (e.g., with a contractor, electronically, etc.). The key is that the documentation must be made available to the authorities within a reasonable time. The responsible party is also responsible for evaluating the necessary level of documentation, ensuring it is appropriate for their specific activities and enterprise, and they can utilize documentation systems from suppliers to meet this requirement.

**Framework Demonstration**

The framework acts as a centralised management system for documentation, ensuring that all required information for health, safety, and the environment, related to the technology qualification against requirements, is organised and accessible. The framework facilitates a structured approach to collecting and managing documents related to technology qualification, such as Requirements Proforma, FMECA, Deployment Checklist, and the Technology Qualification Report. These documents collectively demonstrate that all activities are planned and carried out prudently, and compliance with regulations is met.

## Facilities regulation - §48 Well Barriers (Havtil, 2023)

**Regulation**

“Well barriers shall be designed such that well integrity is ensured, and the barrier functions are safeguarded during the well’s lifetime.”

“Well barriers shall be designed such that unintended well influx and outflow to the external environment is prevented…”

“The well barriers shall be designed such that their performance can be verified.”

**Interpretation**

Well barriers shall be designed to ensure integrity, barrier function and prevent leaks or flow into  our from the well to the environment through life.

Well barriers shall be verifiable.

**Framework Demonstration**

Performance, lifetime (integrity) and verification requirements are identified within the Requirements Proforma.

The qualification FMECA evaluates each well barrier element, within the well barrier envelope and for each function and requirement, with appropriate risk mitigations and qualification actions identified where required.

Verification requirements are identified within the Requirements Proforma and the maturity of the verification procedure is assessed as part of the TRL maturity assessment. Verification procedures should also be defined within the deployment checklist. Failure modes related to verification should be assessed in the qualification FMECA.

Framework guidance recommends that all life cycle and operation phases are considered, including verification.



## Guidelines to Facilities regulation - §48 Well Barriers (Havtil, 2023)

**Guideline**

“The well’s life span as mentioned in the first subsection, means time in use and time subsequent to permanent plugging and abandonment.”

“Verification of the performance of well barriers as mentioned in the final subsection, can be based on pressure testing, testing of accessibility, response time and leakage rates, as well as observation of physical properties.”

**Interpretation**

Well’s lifetime is assumed to be in perpetuity.

Standard methods for verification are suitable, or specific observation of physical properties of the well barrier element (e.g. CBL).

**Framework Demonstration**

Failure Mechanisms which may lead to a degradation of function over time should be identified within the Qualification FMECA, and subsequent qualification actions identified to demonstrate the mechanisms do not affect the performance and lifetime of the well barrier.

Verification requirements are identified within the Requirements Proforma and TRL maturity assessment.

Framework includes a deployment checklist template for identified technologies to support verification.

## Facilities Regulation - §9 Qualification of new technology and new methods (Havtil, 2023)

**Regulation**

“Where the petroleum activities entail use of new technology or new methods, criteria shall be drawn up for development, testing and use so that the requirements for health, safety and the environment are fulfilled. The criteria shall be representative for the relevant conditions of use, and the technology or methods shall be adapted to already accepted solutions.

The qualification or testing shall demonstrate that applicable requirements can be fulfilled using the relevant new technology or methods.”

**Interpretation**

Technologies must be proven for the application.

Qualification and Testing shall demonstrate requirements can be met.

**Framework Demonstration**

Technology Qualification Processes (such as DNV-RP-A203), and this Framework, describe a systematic process to identify requirements, which includes health, safety and the environment, and subsequent qualification activities and testing to demonstrate requirements can be met with the required confidence.

Identification of the representative conditions (downhole conditions during installation, verification and long-term integrity) are defined within the Requirements Proforma against which the technology must be demonstrated.

### Guidelines to Facilities regulation - §48 Well Barriers (Havtil, 2023)

**Guideline**

"DNVGL RP-A203 and OEUK Use of Barrier Materials in Well Decommissioning Guidelines Issue 3 can be used to fulfil the requirements regarding methods for the qualification of new technology."

**Interpretation**

Technology Qualification Processes like DNV-RP-A203 and Use of Barrier Materials in Well Decommissioning Guidelines Issue 3 can be used as guidance for the qualification of alternative materials.

**Framework Demonstration**

The Framework references and aligns to both and applies these processes to the application of Alternative Well Barrier Materials.

### Management Regulations - §17 Risk analyses and emergency preparedness assessments (Havtil, 2023)

**Regulation**

"Risk analyses shall be carried out and form part of the basis for making decisions when e.g.:

a) Identifying the need for and function of necessary barriers, cf. Sections 4 and 5,

b) Identifying specific performance requirements of barrier functions and barrier elements, including which accident loads are to be used as a basis for designing and operating the installation/facility, systems and/or equipment, cf. Section 5."

**Interpretation**

Function and performance requirements of barriers shall be decided alongside and as a result of conducting whole well barrier envelope risk-based analysis.

**Framework Demonstration**

The requirements proforma defines the specific requirements for the well barrier, which includes the function of the alternative material barrier within the context of the whole well abandonment design.

The FMECA template requires that requirements are defined for each failure mode, including examples which the requirements may relate to.

### Guidelines to Management Regulations - §17 Risk analyses and emergency preparedness assessments (Havtil, 2023)

**Guideline**

"c) The emergency preparedness analysis shall result in a description of the contingency requirements in all barriers, according to Section 73 of the Activities Regulations. The contingency requirements in the different barriers should be calculated based on statistical simulations of drift and dispersion. The expected weathering and amount of emulsion into each barrier should be specified."

**Interpretation**

Health and safety-related emergency preparedness should be prepared for the installation of any well barrier system, with contingencies requirements identified according to Section 73 of the Activities Regulations.

**Framework Demonstration**

The Technology Maturity Assessment worksheet suggests that a "consequence assessment should consider risk to people and the environment, either within the FMECA, or alternative safety risk assessment e.g. HAZOP", as part of fulfilling the requirements to claim TRL 7, and before deployment as part of the entire well abandonment design "in the actual downhole environment".

Note: Contingency requirements for all barriers should be considered for any well barrier systems and installation and is not specific to new well barrier technologies and materials.



## Appendix 1.3.
## United Kingdom Guidelines

In the UK the following guidelines are relevant to advise on the qualification of new well barrier materials and elements.

### OEUK – Well Decommissioning Guidelines – Issue 7 (OEUK, 2022)

**3.2 Material Requirements for Permanent Barriers**

"The main characteristics of placed barrier materials (not limited to cement) should be as follows:

- Impermeable – to prevent flow of fluids through the material.
- Provide an interface seal – to prevent flow of fluids around the barrier; the material provides a seal along the interface with adjacent materials such as steel pipe or rock; risks of shrinkage and de-bonding are to be considered.
- Remain at the intended position and depth in the well.
- Long-term integrity – long-lasting isolation characteristics of the material, not significantly deteriorating over the design life of the barrier, while still meeting design criteria; risks of cracks and de-bonding over time are to be considered.
- Resistance to downhole fluids (e.g. CO2, H2S, hydrocarbons, brine, magnesium) at foreseeable pressures and temperatures.
- Mechanical properties suitable to accommodate loads at foreseeable temperatures and pressures. If applicable consider changes in service over the entire life cycle of the well (e.g. due to conversion of producers to water injectors, steam injection, gas storage, carbon storage unconsolidated formations etc.).
- Compatibility of barrier material with adjacent geology

Separate guidelines have been compiled for the qualification of barrier materials which are to be placed (see OEUK Guidelines on use of Barrier Materials in Well Decommissioning).

The barrier functional and performance acceptance criteria must be specified for the following barrier characteristics:

- Sealing
- Position
- Placeability
- Durability

The condition and suitability of existing materials in the well should be considered when forming part of a permanent barrier, e.g. scale, corrosion, mud solids, plastic coated tubulars, GRE lined tubulars, encapsulation, control lines and cable."

**Interpretation**

Materials chosen for permanent well barriers should provide an appropriate seal that is compatible with the surrounding environment and must stay in intended position under all conditions that can be seen throughout the well's life (perpetuity).

OEUK Guidelines on use of Barrier Materials in Well Decommissioning (Issue 3) can be used as guidance for the qualification of alternative materials.

**Framework Demonstration**

The Requirements Proforma requires that definitions are provided for each required barrier characteristic, namely maintaining a seal, maintaining position, effective installation and for the long-term integrity. Similarly, the provided Requirements Proforma worksheet template include sections which relate to the downhole environment (e.g. fluids, composition, temperatures and pressures), the specific well barrier materials including annular materials within the well barrier envelope and the through life integrity requirements.

OEUK Guidelines on use of Barrier Materials in Well Decommissioning (Issue 3) and this Framework, both reference DNV-RP-A203, and describe a systematic process to identify requirements, which includes health, safety and the environment, and subsequent qualification activities and testing to demonstrate requirements can be met with the required confidence.

## OEUK – Well Decommissioning Guidelines – Issue 7 (OEUK, 2022)

**3.3 Number of Permanent Barriers**

"All penetrated zones with flow potential, that have been identified as requiring isolation, should be isolated from surface or seabed by a minimum of one permanent barrier, or two as appropriate. Where cross flow is deemed unacceptable, zones should be isolated from each other.

The actual number of barriers required should be determined by risk assessment and may differ from the numbers below:

The actual number of barriers required should be determined by risk assessment and may differ from the numbers below:

- One permanent barrier from surface or seabed should be considered if a zone requiring isolation is water-bearing and has flow potential.
- Two permanent barriers from surface or seabed are recommended if a zone requiring isolation is hydrocarbon-bearing OR water bearing and significantly over-pressured.

Operators should assess barrier requirements using the following considerations:

- Differential pressure across the barrier
- Impact of single point failure
- Robustness of barrier placement and verification

The two permanent barriers may be combined into a single large permanent barrier (combination barrier), provided it is as effective and reliable as the two barriers and is an appropriate method to achieve the objectives that two barriers would otherwise have provided."

**Interpretation**

Barrier requirements should be assessed by Operators and should consider the differential pressure (across the barrier), single point failures and the robustness of the installation process to install and verify a barrier successfully.

A single large barrier, of sufficient length, may also be used instead of two barriers, if it can be verified as effective and reliable.

**Framework Demonstration**

The Requirements Proforma contains sections which are initially populated by a Technology Provider and subsequently individually assessed by the Operator against the identified requirements. This must be completed and checked by the Operator.

The Requirements Proforma includes sections for the differential pressure, and entire separate worksheets for installation and verification requirements to be captured.

The FMECA should help identify potential single point failures and it will also support the creation of a robust installation and verification process.

The FMECA and reliability assessment of a single large barrier can potentially demonstrate that a single larger barrier is as "effective and reliable" as two barriers.

**Note that this Framework does not provide guidance on the overall well decommissioning design for the purposes of the abandonment of wells and only applies to the qualification of individual well barriers within the overall system.**



## OEUK – Well Decommissioning Guidelines – Issue 7 (OEUK, 2022)

**Length Requirements of Permanent Barriers**

**3.4.2.3 Alternative Materials**

"It is recognised that different barrier materials are in development and will emerge as alternatives to cement. These materials will require assessment and it is anticipated that required lengths of these materials will be different to those of cement.

If it can be verified that the cumulative length of the resulting seal provided by the alternative material is adequate to prevent flow of the fluids below at the maximum anticipated pressures, then such a seal is acceptable as a replacement for a good annular cement bond. The internal barrier material should be adjacent to the annular isolation, or can itself form the annular isolation as well, provided there is sufficient cumulative length above the zone with flow potential. Separate guidelines have been compiled for the qualification of barrier materials which are to be placed (See OEUK Guidelines for the use of Barrier Materials in Well Decommissioning)."

**Interpretation**

Alternative material barriers may be used if assessed and qualified to prevent the flow of present fluids at the maximum anticipated pressures.

OEUK Guidelines on use of Barrier Materials in Well Decommissioning (Issue 3) can be used as guidance for the qualification of alternative materials.

**Framework Demonstration**

This Framework supports the qualification of well barrier materials, including alternative well barrier materials. The Requirements Proforma will define the operating conditions for the well barrier, including anticipated pressure at all life-cycle stages, including long term integrity. This then informs the assessment of mechanisms by which the requirements could fail to be met and the identification of testing and analysis to qualify the material to demonstrate it can meet all the identified requirements with minimal residual risk.

OEUK Guidelines on use of Barrier Materials in Well Decommissioning (Issue 3) is referenced and this Framework is aligned to that guideline document.

## OEUK – Well Decommissioning Guidelines – Issue 7 (OEUK, 2022)

**Position Requirements of Permanent Barriers**

"The first barrier above the zone with flow potential is referred to as the primary barrier; the next barrier above the zone with flow potential, where required, is referred to as the secondary barrier.

A permanent barrier should;

- Be set above the zone with flow potential across a suitable cap rock.
- Extend across the full cross section of the well and include all annuli (Rock to Rock).
- Have a formation fracture strength at the base of the barrier in excess of the maximum anticipated pressure from the zone being isolated.

A suitable cap rock is impermeable, laterally continuous and has adequate strength and thickness to contain the maximum anticipated pressure from the zone being isolated.

Note 1: Consideration should be given to the location of the barrier and formation strength along the length of the barrier."

**Interpretation**

A permanent barrier should be set above the zone of flow potential and extend across the full cross section of the well and include all annuli (Rock to Rock).

**Framework Demonstration**

The Requirements Proforma defines the requirements for the well barrier including all interfaces and elements (e.g. annuli materials and formation), which comprise the well barrier envelope.

**Note that requirements related to zones of flow potential is not directly considered by this Framework, as this should be considered as part of an overall well decommissioning design.**

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

**2.1 Risk-based Evaluation**

"A risk-based methodology should be applied for the identification and selection of suitable well barrier materials. A systematic process, such as technology qualification, will demonstrate for the well barrier that:

- The function, performance and required reliability are met;
- The health, safety and environmental risks are acceptable; and
- Any level of uncertainty is acknowledged.

Guidance on technology qualification is typically provided by certifying authorities, Standard organisations and industry organisations, examples include:

- Technology qualification DNV-RP-A203,
- Recommended practice on Subsea Equipment Qualification API 17Q,
- Bureau Veritas Guidance Note NI525 DT R00,
- Petroleum, petrochemical and natural gas industries – Production assurance and reliability management ISO 20815,
- Lloyds Register – Guidance Notes for Technology Qualification"

**Interpretation**

Technology Qualification Processes such as DNV-RP-A203 and API 17Q, for example, can be used as guidance for the qualification of alternative materials.

**Framework Demonstration**

Technology Qualification Processes (such as DNV-RP-A203), and this Framework, describe a systematic process to identify requirements, which includes health, safety and the environment, and subsequent qualification activities and testing to demonstrate requirements can be met with the required confidence.

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

**2.1.1 Defining the Qualification Boundary**

"The barrier material developer and provider should work with the operator to agree a statement of requirements for the well application. If the barrier material has not been previously qualified for the intended application, then consideration should be given to an appropriate qualification process. These requirements should define the expected operating environment, well barrier envelope, well barrier elements, and the interfaces within the systems.

The barrier functional and performance acceptance criteria should be specified for the following barrier characteristics,

- Sealing (Refer to Chapter 3.1.3 Dimensional Stability)
- Position
- Placeability
- Durability"

**Interpretation**

Performance criteria relating to material characteristics (functions) such a sealing, position, placeability and durability, should be specified by the material developer and provider and in agreement with the Operator for a specific well application, as the basis for ensuring the barrier material is suitably qualified for the application.

**Framework Demonstration**

The Requirements Proforma contains sections which are initially populated by a Technology Provider and subsequently individually assessed by the Operator against the identified requirements. This must be completed and checked by the Operator.

The Requirements Proforma requires that details are provided for each requirement, namely maintaining a seal, maintaining position, effective installation (placeability) and for the long-term integrity (durability) in the context of the intended specific application.



## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

**2.1.2 Technology Maturity**

"In general, the qualification of a barrier material is only applicable to the well envelope and qualification boundary for which it has been previously qualified. Therefore, whether a barrier material has been previously qualified, or yet to be qualified, the intended application of the barrier should be assessed in relation to the barrier nature or maturity."

"During the development of a barrier material, the maturity of the technology readiness is typically expressed as a technology readiness level (TRL)."

"Whilst the qualification of the barrier material(s) is of primary importance, consideration should also be given to the deployment system, the interaction of the barrier with other well barrier elements in the downhole environment and the installation process. These may all form part of a rigorous barrier qualification exercise prior to field deployment."

**Interpretation**

The technology maturity of a well barrier material, whether previously qualified or not, should be assessed for the intended barrier application. The technology maturity may be expressed using a technology readiness level (TRL). It may be necessary to conduct an overall barrier qualification to encompass the complete well barrier envelope, deployment system and tooling, and verification process.

**Framework Demonstration**

The Technology Maturity Assessment step of the Framework will assess the claimed technology readiness level of the well barrier material and system/process to install and verify the well barrier downhole, in the context of the technology requirements as defined in the Requirements Proforma. The provided worksheet defines 5 tasks and activities per TRL level which should have been completed to be able to claim completeness of a specific TRL, and an overall system TRL level.

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

**2.1.3 Failure Mode Assessment**

"There are various tools available to assess the failure modes of a technology. One widely used technique is a Failure Modes, Effect and Criticality Analysis (FMECA). It is an assessment method used for systematically identifying and evaluating how a system, sub-system or component may fail, and is applicable across the lifecycle of the technology after the R&D stage to deployment."

**Interpretation**

Failure modes of the technology should be assessed using techniques such as FMECA.

**Framework Demonstration**

The framework clearly outlines the use of FMECA techniques to assess failure modes of the technology. Qualification actions and risk mitigations arising from the FMECA will support the management of risk. A FMECA template has been provided, which has been prepopulated with example failure modes and mechanisms to aid developers in their own FMECA assessment.

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

### 2.1.4 Reliability and Risk Analysis

"To support reliability or life expectancy (e.g. MTTF) of a barrier, it may be necessary to carry out a reliability analysis to predict the likelihood of failure. When combined with methods to predict the consequence of a failure, an estimate of the risk of failure can also be made. Typical methods which should be considered to better understand and estimate the reliability of a system include Bow Tie Analysis, Fault Tree Analysis (FTA), Event Tree analysis (ETA) and Reliability Block Diagrams (RBD). These methods should be able to represent a barrier which may consist of multiple well barrier elements (e.g. plug, casing, annulus cement, formation etc.) and interfaces (micro annuli) and the associated failure modes for each."

"Risk analysis may incorporate various techniques to assist with the quantification of both the likelihood and consequence (severity) of a failure and provide a prediction of likely leak pathway (Tools are available from both industry and research organisation) and can be combined with oil drift, or gas plume analysis to assess the likely consequence of a leak."

**Interpretation**

Risk analysis techniques such as FTA and ETA should be carried out to predict the likelihood of failure of the complete well barrier envelope.

**Framework Demonstration**

The Technology Maturity Assessment worksheet suggests that appropriate system reliability (e.g. FTA) analysis should be identified as part of claiming TRL 4, and these activities should be completed as part of claiming TRL 5. This applies to the entire well barrier system (i.e. well barrier envelope).

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

### 2.1.5 Qualification Plan

"Whilst it is expected that a permanent barrier will be verified in the field, placement of such a barrier must be underpinned by qualification of the materials used, the design of the barrier and the deployment method."

**Interpretation**

Prior to barrier verification in the field, the materials used, barrier design and deployment methods must be qualified, to demonstrate that the material can be placed effectively to confidently achieve the required physical properties.

**Framework Demonstration**

This Framework describes a systematic process to qualify the materials, well barrier design and deployment method, including building confidence that the correct physical properties can be reliably achieved through its deployment to position.

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

### 2.1.6 Evaluation of Results

"The results from the test activities undertaken as part of the qualification plan should be assessed against the intended performance and related back to the relevant boundary envelope and failure modes. The FMECA document should be updated on completion of activities in the qualification plan, and the mitigated risks evaluated for the relevant failure modes.

The limiting material characteristics and functional performance should be clearly identified. When experience is used as proof of fulfilment of the specifications and reasonable "margins", this should be documented."

**Interpretation**

Activities identified in the Qualification Plan need to be completed and the results assessed against ,the requirements and to ensure the mitigated risks are acceptable. The FMECA should be updated.

The well barrier envelope and application boundary should be defined, including any specific limits, characteristics and functional performance. If actual use of the well barrier is used as a demonstration of specifications, reasonable safety margins should be applied and documented.

**Framework Demonstration**

The final step of the Framework, Technology Qualification evidence and Deployment Checklist, requires the assessment of the qualification evidence to support the claims of meeting the technology requirements as defined in the Requirements Proforma, and assessed in the FMECA for the specific well application.



## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

### 2.1.7 Managing Residual Uncertainty

"The residual uncertainty is the risk of the well barrier failing after deployment once all mitigation actions for the identified failure modes have been demonstrated to be acceptable. The residual risk will need to be accepted by the end user and satisfy their risk acceptance criteria.

Before a technology is deployed, an assessment of the residual uncertainty should be made. This can, where appropriate, include a comparative risk assessment against current industry good practice. This can be found in OEUK's Well Decommissioning Guidelines Issue 7. Prior to field deployment, a safety risk assessment of the barrier technology should be undertaken."

**Interpretation**

Following the completion of the actions identified in the Qualification Plan, the FMECA should be updated and mitigated risks assessed based on the evidence.

A safety risk assessment (e.g. HAZID, HAZOP) should be conducted prior to field deployment.

**Framework Demonstration**

The final step of the Framework, Technology Qualification evidence and Deployment Checklist, requires the assessment of the qualification evidence to support the claims of meeting the technology requirements as defined in the Requirements Proforma, and assessed in the FMECA in the context of the specific well application. The FMECA should be updated and mitigated risks assessed.

The Technology Maturity Assessment worksheet suggests that a "consequence assessment should consider risk to people and the environment, either within the FMECA, or alternative safety risk assessment e.g. HAZOP", as part of fulfilling the requirements to claim TRL 7, and before deployment "in the actual downhole environment".

## OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

### 2.1.8 Documentation and Assurance Requirements

"To ensure that this process is followed rigorously, it should be documented and where appropriate facilitated by an independent expert(s). The available documentation and insight into the qualification process may follow three alternatives:

- An open qualification scheme - all information is available.
- The qualification documentation is made available to a third party recognised by the involved parties.
- The original qualification documentation is not accessible. Full function and endurance tests according to the specifications should document the qualification, in addition to the supplier's statement of qualification. This may imply more extensive testing than the former. These tests should demonstrate acceptable margins for all conditions. It may imply testing of a sufficient number of batches to develop statistically representative data.

It is recommended that the qualification method, qualification steps and tests are agreed beforehand with potential users and relevant stakeholders."

**Interpretation**

Documentation should be made available to demonstrate that the qualification process has been followed rigorously. Further to this, facilitation by independent experts may be appropriate.

Potential users of the technology and relevant stakeholders (especially the Technology Developer or provider) should agree on the qualification method, steps and tests, including how documentation is made available.

**Framework Demonstration**

This Framework is a technology qualification process. The Requirements Proforma, Technology Maturity Assessment and FMECA worksheets should provide a suitable level of rigour, if completed fully, in alignment with the expectations of the OEUK Use of Barrier Materials in Well Decommissioning Guidelines.

The Framework, document templates and guidance documents have been developed by a consortium of industry experts.

The document templates have been developed with input from Technology Developers and Operators, and attempts to balance the protection of intellectual property of the Technology Developer and the need to share sufficient evidence to provide confidence to end users of the technology to meet their requirements.

### OEUK – Use of Barrier Materials in Well Decommissioning Guidelines – Issue 3 (OEUK, 2022)

**3 Evaluation of Permanent Barriers**

"The performance requirements of a permanent barrier will be dictated by the operating conditions that it will experience, principally, pressure temperature and fluids. It is therefore necessary to characterise certain properties of the prospective barrier material to ensure that it is appropriate for the application.

**Material Characteristics**

Material Permeability

Fluids Compatibility

Dimensional Stability

Mechanical Properties

Time Dependent Integrity

**Downhole Considerations**

Wellbore Geometry & Condition

Barrier Envelope Integrity

Testing at Simulated Downhole Environment

Placement of Permanent Barriers

Candidate Well Selection"

**Interpretation**

Material characteristics should be defined with consideration of the downhole conditions and to ensure that these are suitable for the intended barrier application.

**Framework Demonstration**

The Requirements Proforma worksheet template includes sections for capturing details of the downhole environment, including well geometry and condition, fluids, composition, temperatures and pressures. Characteristics of the material are defined in the context of the intended well barrier, sealing, maintaining position, installation and long-term integrity. The material properties and characterisation necessary to support the qualification of the well barrier material and its deployment with the intended installation tooling should be identified as outcomes of the FMECA, if not yet known, or not previously required.

### Oil & Gas UK – Guidelines on Qualification of Materials for the Abandonment of Wells – Issue 2 (O&GUK, 2015)[1]

**9 Material types – specific experimental work plans**

"The following section identifies appropriate work plans for qualification testing, based on the most likely failure modes for each material type. It should be stressed that the suggested work plans for each material type, are based on the typical behaviour of such materials, and that other tests may need to be included to address non-typical material characteristics."

**Interpretation**

The guideline provides a starting point for material qualification testing, but it's the user's responsibility to critically evaluate the specific material and, if necessary, design additional tests to ensure its suitability and prevent unexpected failures.

**Framework Demonstration**

First, the Requirements Proforma section of the framework is used to identify the specific material intended for well abandonment and its unique characteristics. This step prompts an evaluation beyond the typical, considering factors like material composition, manufacturing process, and environmental conditions that might lead to non-typical behaviour. Next the FMECA serves as the primary tool for identifying potential failure modes and mechanisms for the specific material in the intended environment and based on the findings a specific testing qualification plan can be determined. Material properties and potential failure mechanisms identified in the Guideline are also identified in both the Requirements Proforma and FMECA templates for completeness.

[1] Although superseded, Issue 2 is included here because of the detailed materials qualification testing guidance it offers.



## Appendix 1.4.
## Norway Guidelines

In Norway the following guidelines are relevant to advise on the qualification of new well barrier materials and elements.

### NORSOK D-010:2021+AC2:2021 Well integrity in drilling and well operations (NORSOK, 2021)

**Defining well barriers**

"The well barrier envelopes shall be defined prior to commencement of an activity by identifying all required well barrier elements (WBE) to be in place.

The identified WBE's shall comply with their specific acceptance criteria (see EAC tables)"

**Interpretation**

The well barrier envelope must be defined which includes all well barrier elements, including formation, casing, annuli and its contents, cement, and the well barrier material. All well barrier elements shall comply with the acceptance criteria defined in the relevant Element Acceptance Criteria (EAC) table.

**Framework Demonstration**

The Requirements Proforma specifies that all well barrier elements within the well barrier envelope should be defined, and the relevant requirements associated which each well barrier element identified. The well barrier elements include formation, casing, annuli and contents, cement, and the well barrier material being qualified. The Framework suggests that each well barrier element and their interface with the well barrier material should be assessed within the FMECA to ensure all technical risks and qualification actions are identified.

### NORSOK D-010:2021+AC2:2021 Well integrity in drilling and well operations (NORSOK, 2021)

**Minimum number of well barrier envelopes in well construction-, production / injectionphases and after permanent P&A**

"For a formation to qualify as a WBE, the formation integrity shall be defined and documented.

Table 3 lists the integrity requirements that apply:

**Table 3 - Formation integrity requirements**

| Well type/activities | Minimum formation integrity | |
|---|---|---|
| | New well (after D-010:2013 rev4) | Existing wells (before D-010:2013 rev4) |
| Exploration wells (all activities including pernament abandonment) | Formation pressure integrity can be verified by PIT/FIT or LOT. The measured values shall be sufficient for required kick margin, for dynamic kill of a blowout through a relief well and for permanent abandonment requiremnets. | |
| Production wells - drilling activities and activities with mud in hole | | |
| Production wells - completion activities with solid-free fluid, production/injection and abandonment activities | Minimum formation stress/fracture closure pressure (FCP) shall exceed the maximum wellbore pressure at formation depth. - see table 6 for well design pressure basis. | The formation integrity pressure (in the interval between LOP and FCP, see Figure 6) used in the original design may be used. The original design values shall be re-assessed proir to permanent abandonment of the wells(s). |

**Interpretation**

For a formation to qualify as a WBE for permanent abandonment, the minimum formation strength or fracture closure pressure shall be greater than the maximum anticipated pressure at that depth.

**Framework Demonstration**

The formation adjacent to the well barrier should be identified and defined in the Requirements Proforma. The formation should be assessed within the FMECA against all required functions and life-cycle stages where appropriate, in a similar manner all other well barrier elements comprising the well barrier envelope should also be assessed.

## NORSOK D-010:2021+AC2:2021 Well integrity in drilling and well operations (NORSOK, 2021)

**Element acceptance criteria (EAC) tables**

"To qualify as a WBE, a well component shall conform to the acceptance criteria requirements specified in its corresponding EAC table.

EACs shall be in place for all WBEs used.

General technical and operational requirements and guidelines relating to WBEs are collated in the EAC tables in Annex C, which shall be applicable for all types of activities and operations. A new EAC table shall be developed in cases where an EAC table does not exist for a specific WBE.

The level of detail shall be defined by the user.

**Table 5 - EAC table description**

| Features | Acceptance criteria | See |
|---|---|---|
| A. Description | This is a description of the WBE | |
| B. Function | This describes the main function of this WBE | |
| C. Design (capacity, rating, and function), construction and selection | For WBEstat are constructed in the field (e.g. drilling fluid, cement), this should describe<br><br>**a)** design criteria, such as maximal load conditions that the WBE shall withstand and other functional requirements for the period that the WBE will be used:<br>**b)** construction requirements for the WBE or its sub-components and will in most cases consist of references to normative standards.<br><br>For WBEs that are pre-manufactured (production packer, DHSV), the focus should be on selection parameters for choosing the right equipment and proper field installation | Name of specific references |
| D. Initial test and verification | This describes the methodology for verifying that the WBE is ready for use and being accepted as part of a well bariier envelope | |
| E. Use | The describes proper use of the WBE to ensure that its function is maintained during execution of activities and operations | |
| F. Monitoring (regular surveillance, testing and verification) | This describes the methods for verifying that the WBE continues to be intact and fulfils the design criteria | |
| G. Common WBE | This describes additional criteria to the above when this element is a common WBE | |

**Interpretation**

A novel well barrier material which forms a WBE, will require a new EAC table if it does not exist.

**Framework Demonstration**

The Framework has identified the need for an EAC table for the specific WBE being qualified, if it does not exist yet, and if the well barrier is to be deployed on the Norwegian Continental Shelf.

## NORSOK Z-013 – Risk and emergency preparedness assessment (NORSOK, 2024)

**7.5.2 Analysis Consequences**

"The following requirements apply:

**a)** The initiating events to be analysed shall be determined by the hazard identification as specified in 7.3 and listed initiated events as given in 5.4.3;

**b)** Event sequences shall be explicitly modelled using suitable tools such as event tree or similar. If event tree is used, the nodes shall reflect important barriers and premises that determine outcomes. Not all barriers need to be modelled as nodes, but the most important barriers shall be explicitly modelled. The tool should facilitate sensitivity analysis with respect to barrier functionality and/or reliability;"

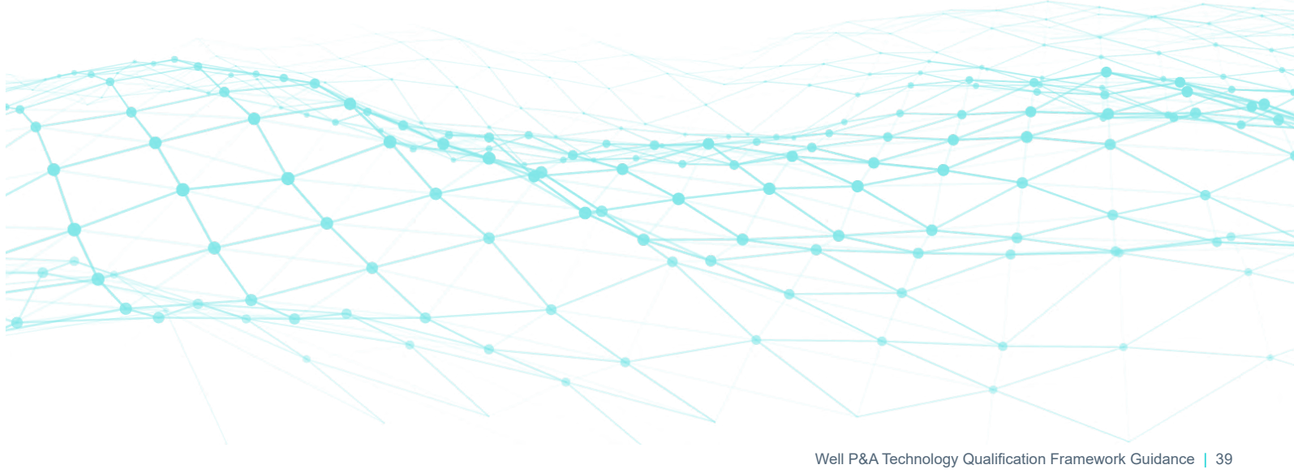
**Interpretation**

Well barrier analysis and performance should be fed as an input to the overall system risk assessment. The barrier elements should be included as specific nodes in tools such as event tree analysis (ETA) and included sensitivity cases for barrier functionality or reliability.

**Framework Demonstration**

The Technology Maturity Assessment worksheet suggests that appropriate system reliability (e.g. FTA, ETA) analysis should be identified as part of claiming TRL 4, and these activities should be completed as part of claiming TRL 5. This applies to the entire well barrier system (i.e. well barrier envelope including but not limited to the alternative barrier material).

The Technology Maturity Assessment worksheet suggests that a "consequence assessment should consider risk to people and the environment, either within the FMECA, or alternative safety risk assessment e.g. HAZOP", as part of fulfilling the requirements to claim TRL 7, and before deployment "in the actual downhole environment".



# Appendix 2.
# Example EAC table for Alternative Barrier Materials

Norsok D-010 contains an EAC table for Alternative Barrier Materials [Table 55 (Norsok, 2021)] and is shown in Table A13.1 below. This is a generic EAC covering any alternative barrier material other than cement, and provides the acceptance criteria related to the design and construction, testing, verification and monitoring requirements. No length requirements are defined, however the length of an alternative material barrier will need to be equivalent to the seal which can be achieved by a cement plug. In this table, both the DNV-RP-A203 and Oil & Gas Uk - Guidelines on Qualification of Materials for Abandonment of Wells Issue 2 [14] are referenced as example processes and guidelines. While Issue 3 (See [2]) has since been published, Issue 2 remains as a resource for identifying relevant testing requirements across a range of material types.

Table A13.1 EAC Table 55 Alternative Barrier Materials (Norsok, 2021)

**Table C.55 - EAC Table 55 - Alternative barrier material**

| Features | Acceptance criteria | See |
|---|---|---|
| A<br>Description | The well barrier element (WBE) consists of a barrier material in solid or semi solid state or a suspension thereof that forms a barrier in the wellbore, inside production string or casing/liner, or behind casing/liner.<br>Note 1: This EAC table only applies to barrier materials other than cement.<br>Note 2: This table covers the requirements to qualify an alternative/new barrier material. | NORSOK D-001 |
| B<br>Function | The purpose of the plug material is to prevent flow of formation fluids inside a wellbore, between formation zones and/or to the environment outside the well construction to surface/seabed environment. | |
| C<br>Design construction selection | 1) A new barrier material shall undergo a qualification process as specified in (or similar to)<br>UK Oil and Gas, Guidelines on qualification off materials for the abadonment of wells (62) and/or<br>DNVGL RP-A203 “Qualification of New Technology” (59) That Qualification process shall be documented.<br>2) Prior to installation, the properties of the barrier material shall have been verified by laboratory testing to ensure functional, sealing, and mechanical capabilities. This shall be documented in Product certificate issued by the manufacturing plant/lab and subsequently approved by the end user.<br>3) Barrier material used to isolate sources of inflow containing hydrocarbons shall be designed to prevent gas migration and be suitable for the well environment (e.g. temperature, $CO_2$, $H_2S$)<br>4) The barrier material shall be designed for the highest differential pressure and highest downhole temperature expected including installation and test loads and shall be able to withstand pressure from below without upward movement.<br>5) If used for permanent abandonment applications, the alternative barrier material shall fulfil the requirements stated in Clause 10, and in particular Table 26, as well as paragraphs 10.3.1, 10.3.2 and 10.6.2.<br>6) The following shall be considered for any new barrier material to be used:<br>a) Foundation and anchoring for the plug material;<br>b) Sensitivity to loss of hydrostatic pressure;<br>c) Sensitivityto contamination from wellbore and/or formation fluids;<br>d) Ability to remove the material in the event that a well shall be re-entered;<br>e) The risk of fluidization or disintegration of the barrier material shall be assessed<br>f) If an alternative material is used in a well for the first time, its installation shall be verified in the same manner as for the tests that were performed as part of the qualification process. | UK Oil and Gas, Guidelines on qualification off materials for the abadonment of wells (62)<br><br>DNVGL RP-A203 (59) |
| | The minimum barrier length shall be determined based on a sealing capability that is documented to be equal to or greater than what is provided by the required cement length in EAC Table 22 and EAC Table 24. The minimum WBE material length shall be documented to fulfil requirements set in 10.6.3 | |
| D<br>Initial test and verification | 1) Internal WBE shall be verified using at least one of the methods below:<br>a) Pressure test, either in the direction of flow or from above. If the WBE is set on a pressure tested foundation, a pressure test is not required. It shall be verified by tagging;<br>b) Tag/load test with drill pipe or wireline;<br>c) Any other alternative verification method that is documented and proven to be suitable for the particular type of alternative barrier material being used.<br><br>2) External WBE shall be vertified using at least one of the methods below:<br>a) Bonding logs. Logging methods/tools shall be selected based on ability to provide data for verification of bonding. The measurements shall provide azimuthal/ segmented data. The logs shall be verified by qualified personnel and documented;<br>b) Application of a pressure differential across the interval;<br>c) Downhole acoustic leak-off test;<br>d) Any other alternative verification method that is documented and proven to be suitable for the particular type of alternative barrier amterial being used<br><br>3) The installation of the alternative material WBE shall be verified through evaluation of job execution | |
| E<br>Use | None | |
| F<br>Monitoring | Monitoring required in the following scenarios:<br>a) First use of a new alternative barrier material<br>b) Temporary Abandonment (wells with monitoring) and suspension | |
| G<br>Common well barrier | To be evaluated on a case by case basis after performing an engineering review and a risk assessment. | |

Table is continued on the next page.

# Appendix 3.
# Claiming a Novel Well Barrier is "Proven" at TRL 9

For technologies where lifetime is a major consideration and a key technology issue, lifetime needs to be addressed as part of the technology readiness assessment, and hence the evaluation of the technology as "proven" at TRL 9 [7].

For novel well-barriers, the demonstration of acceptable reliability for through life integrity where "life" is defined in perpetuity (often simplified to 1 million days or 3000 years), the amount of data that would be needed to be gathered to demonstrate acceptable reliability would be unattainable.

The graph in Figure 5 below shows the number of monitored wells required to be able to claim a 3000-year plug life time for a barrier with 99% reliability (i.e. accepting that 1 in 100 barriers may fail after installation and verification through life). The Blue curve represents data for an assumed monitoring period of 1 year after installation, while the orange curve shows a monitoring period of 3 years after plug installation. Clearly the number of wells required to make any reliability claim with any sort of acceptable confidence level (i.e. around 70% confidence) is entirely impracticable.

Therefore, in line with NASA recommendations, life claims need to be addressed by identifying the life limiting failure modes, achieved through understanding and testing life limiting mechanisms and verified through the TRLs by testing/analysis/simulation to understand the resilience to the life-limiting mechanisms:

- **TRL 4** – Identify life-limiting mechanisms and failure modes.
- **TRL 5** – Characterize, by means of test/ analytical model/ simulation, the physics of the life-limiting mechanisms and failure modes
- **TRL 6** – Verify by test/analysis that the technology is resilient to the effects of lifelimiting mechanisms.
- **TRL 8** – Complete life tests.

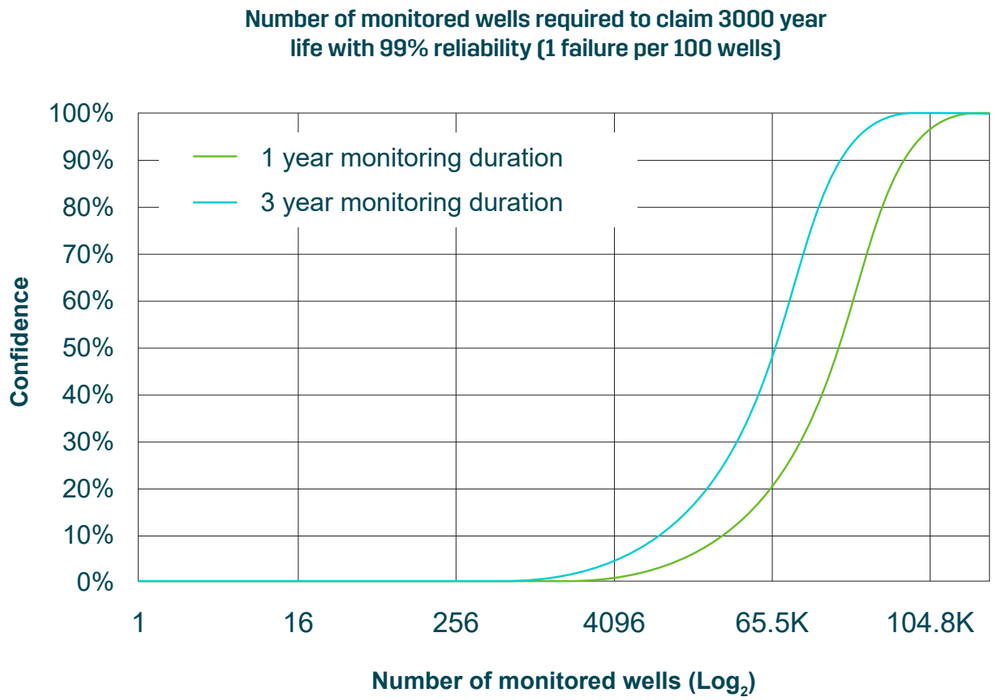



Figure 5: Number of monitored wells required to claim a 3000-year life, based on Chi Squared Analysis.



This relates to understanding the effect of degradation mechanisms through life only, and separately also relies on the successful installation of the well barrier with confidence in achieving the intended material properties. Therefore, assurance of the reliability and confidence of the installation method is as important as understanding the barrier behaviour in perpetuity once correctly installed.

The focus of attention therefore moves away from demonstrating the long-term reliability of the barrier to demonstrating the reliability and confidence in the installation process and tooling. This can be achieved through undertaking successful verification tests of installed barrier, building confidence in the installation method and tooling. Using a Binomial Distribution, Figure 6 illustrates the relationship between number of successful tests, and confidence in a required level of reliability.

## How many tests to Demonstrate Reliability - Binomial Distribution

$$n = \frac{Log(1 - CL)}{Log(R)}$$

Where

- R = test item reliability
- n = number of tests on a single test item or number of test items on a single test
- CL = Confidence level

Number of Verification Tests Required

| Number of failures | Reliability | Confidence | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 95% | 99% | 99.0% |
| 9/10 | 10% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 3 |
| 4/5 | 20% | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 3 | 4 |
| 7/10 | 30% | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 6 |
| 3/5 | 40% | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 5 | 8 |
| 1/2 | 50% | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 4 | 7 | 10 |
| 2/5 | 60% | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 5 | 6 | 9 | 14 |
| 3/10 | 70% | 0 | 0 | 1 | 1 | 1 | 2 | 3 | 3 | 5 | 6 | 8 | 13 | 19 |
| 1/5 | 80% | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 7 | 10 | 13 | 21 | 31 |
| 1/10 | 90% | 0 | 1 | 2 | 3 | 5 | 7 | 9 | 11 | 15 | 22 | 28 | 44 | 66 |
| 1/20 | 95% | 0 | 2 | 4 | 7 | 10 | 14 | 18 | 23 | 31 | 45 | 58 | 90 | 135 |
| 1/100 | 99% | 0 | 10 | 22 | 35 | 51 | 69 | 91 | 120 | 160 | 229 | 298 | 458 | 687 |
| 1/999 | 99.9% | 0 | 105 | 223 | 356 | 511 | 693 | 916 | 1203 | 1609 | 2301 | 2994 | 4603 | 6904 |

Figure 6: Number of tests to demonstrate reliable well barrier installation, based on Binomial Distribution.

This is further illustrated, graphically in Figure 7, which shows that for a lower required reliability, fewer successful tests are required to be able to claim confidence in that level of reliability for the technology. To be able to claim a higher reliability, significantly more tests would be required to claim the same level of confidence.

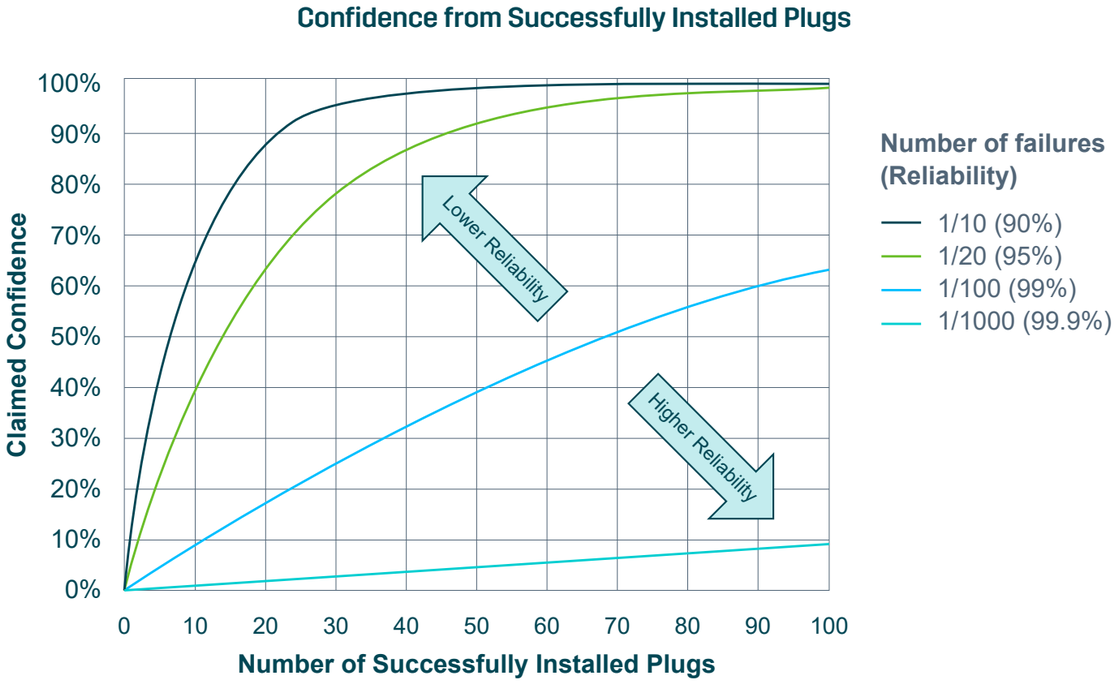
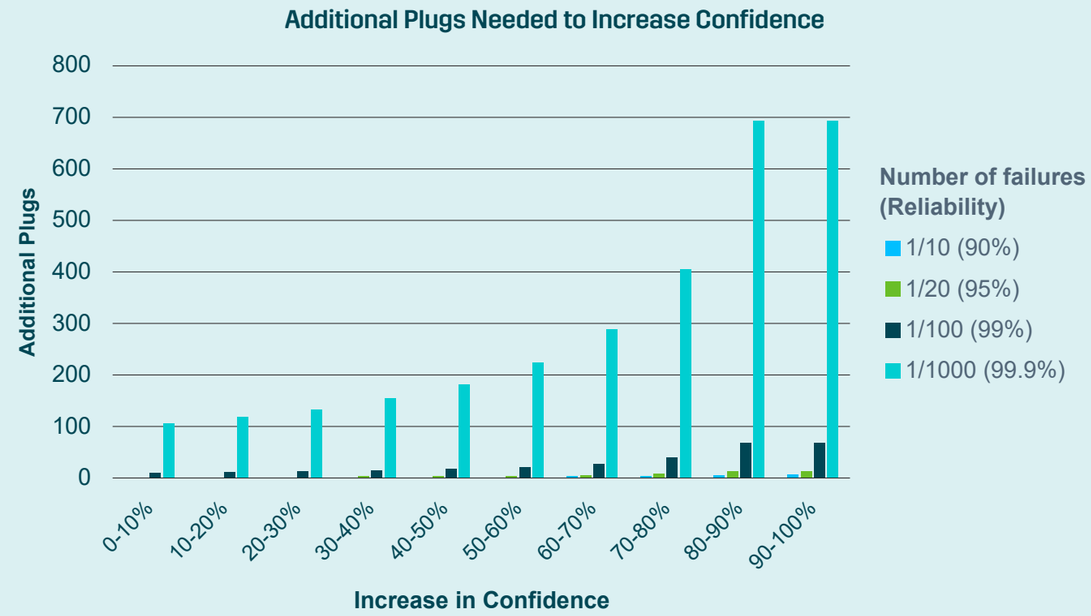



Figure 7: Graphical representation of number of rests to demonstrate reliable well barrier installation, based on Binomial Distribution.



Diminishing returns




In conclusion, then, monitoring cannot practically be used to demonstrate “proven” lifetime / reliability of a barrier to achieve TRL 9.

Demonstration of lifetime achieved through understanding and testing life limiting mechanisms through lower TRLs
Monitoring will provide confidence in successful installation to achieve required properties/characteristics and identification of early life failures.

To claim a well barrier technology is proven, this needs to be made with an agreement of the desired reliability and accepted confidence.

Number of additional verified plugs required to increase confidence increases significantly above >70% confidence i.e. diminishing returns.

Reliability needs to reflect the allowable number of failures during installation and/or verification.

Once verified the plug should be installed such that the material properties are those demonstrated during testing of the identified life limiting degradation mechanisms (as above).

# Appendix 4.
# Deployment Checklist Guidance

## Appendix 4.1:
## Why a Deployment Checklist is recommended

A Deployment Checklist should be prepared as an operational tool to support the verification and installation of alternative well barrier materials. Its purpose is to ensure the material and barrier will perform as intended, in line with established qualification assurance measures.

The checklist template included in the Technology Qualification Framework is influenced by the OEUK Guidelines for the Use of Barrier Materials in Well Decommissioning [2] (See section 4.3 Deployment Good Practices with that guideline) and aligned with the Well Barrier EAC tables as required by NORSOK D-010. It is designed to meet the expectations of both.

The Deployment Checklist Template presents a structured set of example items to guide the creation of tailored deployment checklists for specific technologies and applications. Actual checklist requirements will vary depending on well characteristics, regulatory frameworks, and the selected materials or technologies involved.

A Technology specific Deployment Checklist may be developed by the Technology Developer and may be used as the basis for various well deployments. However, it should be noted that while well and well architectures are likely to be similar to previous deployments for a specific technology, any differences between deployments should be carefully assessed against the original Requirements Proforma, to ensure any new risks or qualification gaps are identified and appropriately managed. The Deployment Checklist should also be updated to address these changes in these situations.

It is important that any requirements identified in the deployment checklist are consistent with the assumed requirements defined within the requirements proforma, FMECA and Technology Maturity assessment. Any differences introduced as part of creating the deployment checklist will require updates and re-assessments of the FMECA and Technology Maturity.

## Appendix 4.2:
## Phases, sections and examples of checklist items

The provided Deployment Checklist is initially broken down into the following operational phases Planning and Preparation; Deployment and Execution; Post-deployment and Reporting; and Qualification Status, and these are further split into sections against which example checklist items have been defined. These sections will be described below, including example items from the checklist.

### Appendix 4.2.1:

### Planning and Preparation Phase

The Planning and Preparation phase section of the Deployment Checklist should be populated to ensure that all technical, regulatory, operational, and safety aspects are thoroughly addressed before deployment of the alternative well barrier. This should include ensuring a detailed review of well data and isolation design, careful selection and qualification checks of materials, and readiness of equipment and procedures is undertaken. Risk assessments, contingency plans, and regulatory compliance will also need to be shown to be established, along with the selection of qualified contractors and trained personnel. Comprehensive logistical planning, permit acquisition, and stakeholder coordination underpin the successful execution of the operation. This effective implementation of this phase sets the foundation for safe, efficient, and compliant deployment and execution.

### Well Data Review

A comprehensive review of well data is essential to ensure the effective deployment of novel well barrier elements. This includes evaluating well construction and intervention records to identify suitable deployment zones, and assessing the suitability of existing well barrier elements such as casing, annuli, and formation at the target depth. The well data review should also involve detailed analysis of well history and integrity data, including pressure tests, annuli pressures, corrosion and cement bond logs, to verify barrier performance and condition. Potential downhole challenges such as restrictions, stuck pipe, or casing damage must be identified. Additionally, the wellbore environment (temperature, pressure, and fluid composition) should be examined to confirm compatibility with the barrier material. All findings must be aligned with applicable regulatory requirements and local guidelines concerning the acceptance and verification of alternative barrier technologies. The completion of each aspect of the review should be captured in the Deployment Checklist and the findings should be included in the Requirements Proforma.

### Tool Selection

If a deployment toolstring is required for the installation of the alternative barrier, then the Deployment Checklist should ensure that the requirements and specification of the toolstring and any other equipment are considered. This involves ensuring that all physical, operational, and logistical aspects of the deployment system are fully defined and compatible with the intended well environment. This includes specifying dimensional requirements and limitations, such as the need for centralisation, and verifying that equipment specifications align with the downhole conditions such as pressure, temperature, and fluid composition at the target depth. Tool string design must be appropriately defined in terms of height, length, and weight limitations. Any transport or storage constraints due to the equipment's size or application must also be addressed. Additionally, power and control requirements should be clearly understood to support reliable operation of the deployment system. The consideration of each of these aspects should be captured in the Deployment Checklist and the identified requirements should be included in the Requirements Proforma.

### Material Selection

Effective material selection relies on the availability and review of comprehensive quality assurance and quality control (QA/QC) documentation for the proposed barrier material. By inclusion in the Deployment Checklist this prompts checks to ensure the material meets the required standards for performance and reliability. Additionally, reference data from laboratory qualification tests or prior in-field deployments should be accessible to support planning, confirm suitability, and reduce operational risk during installation. This will also be documented in the Requirements Proforma and evidence.

### Isolation Design

The isolation design process involves identifying appropriate locations for permanent isolation, particularly to secure zones with flow potential. The design must include a detailed evaluation and qualification of any well barrier elements that will remain in place at the target depth. All cable or control lines within the well must be identified, with clear plans for removal or sealing, if required. Verification of the isolation design should be feasible and robust, and the final design must be reviewed to ensure alignment with the overall isolation objectives and regulatory expectations. These requirements are incorporated into the Requirements Proforma and compliance with the requirements checked off on the Deployment Checklist.

### Detailed Procedure Development

A comprehensive and clearly defined operational procedure is essential for successful deployment. This includes detailed steps covering preparation, running in hole (RIH), installation, and verification, with all tasks, responsibilities, and safety measures explicitly outlined. Supporting documentation such as detailed schematics and drawings of the planned plug and abandonment (P&A) operations must be prepared. Finalised and verified lists of all required materials and equipment should be included. Where applicable, computer models and simulations of the installation process should be used to validate the procedure and anticipate potential issues. Actions arising from the FMECA and/or qualification, requiring specific controls within the procedure(s) will also need to be incorporated. The Deployment Checklist provides a means for ensuring relevant procedures are in place and validated.

### Risk Assessment and Mitigation

The Deployment Checklist template also ensures that a thorough risk management approach is undertaken as an essential process to ensure safe and effective deployment. This includes conducting comprehensive hazard identification and risk assessments (HAZID/HIRA) to evaluate potential operational and environmental risks. Documented contingency plans must be developed for foreseeable issues, such as toolstring failure or the need for spare barrier materials. Appropriate risk mitigation measures should be implemented in advance, and a clear emergency response plan must be established and communicated to all personnel involved in the operation.

### Permits and Approvals

The Deployment Checklist ensures that all required permits and regulatory approvals are secured prior to deployment to ensure full compliance with applicable legal and operational frameworks. Effective communication with relevant regulatory authorities should be established early and maintained throughout the planning and execution phases to address any updates, clarifications, or additional requirements that may arise. Arising requirements should be incorporated into the Requirements Proforma.

### Contractor and Service Provider Selection

The selection of contractors and service providers must be based on demonstrated qualifications, relevant experience, and proven performance. The Deployment Checklist requires checks that clear scopes of work and contractual agreements are established to define responsibilities and expectations. Additionally, contractor competencies and required certifications must be thoroughly verified to ensure compliance with operational and safety standards. Specific requirements on competent personnel for the deployment of the barrier technology should also be specified within the Requirements Proforma.

### Logistics and Mobilisation
Effective logistics and mobilisation planning ensures operational readiness at the deployment site. This includes completing site access arrangements and necessary preparations ahead of operations. The transportation and delivery of all required equipment and materials must be carefully coordinated and executed to support timely and efficient deployment activities. The Deployment Checklist requires that these requirements are identified in good time, while the Requirements Proforma should be used to capture any specific logistics, mobilisation, storage or handling requirements that will need to be met as part of the barrier development, qualification and deployment.

### Personnel Training and Competency
All personnel involved in the deployment must be properly trained on the selected technologies, procedures, and safety protocols. Competency and certification verification should be completed to ensure that individuals meet the required standards for their roles. Specific requirements on personnel should be documented within the Requirements Proforma. The Deployment Checklist should require that these aspects are defined and understood. A pre-job safety meeting must be conducted with all team members to review operational plans, roles, potential hazards, and emergency procedures.

## A 4.2.2 Deployment and Execution Phase

This phase involves inspecting and testing equipment, preparing the wellbore, and deploying the barrier material following approved procedures. Continuous monitoring and quality checks ensure proper placement and performance of the barrier. Verification methods confirm integrity, while thorough documentation and responsible waste management maintain operational accountability and environmental compliance. The Deployment Checklist is intended to provide a mechanism for ensuring each of these checks are successfully undertaken and at the right time.

### Equipment Inspection and Testing
The Deployment Checklist includes the expectation that prior to deployment, a thorough inspection of all equipment must be conducted to confirm readiness and integrity. Functionality testing of critical components, such as pumps, wireline tools, and control systems, is included as essential to ensure reliable operation. Additionally, calibration certificates for all relevant equipment must be reviewed and verified to confirm measurement accuracy and compliance with operational standards.

### Well Intervention and Preparation
Before deploying the barrier material, the establishment and verification of appropriate well control measures is required by the Deployment Checklist to ensure safe operations. The wellbore should be cleaned and conditioned as necessary to remove debris and prepare the environment for installation. Any required downhole tools or equipment must be accurately placed to support the deployment process and ensure proper barrier placement and function.

### Technology Deployment
An important role of the Deployment Checklist within the context of the NZTC qualification framework is to ensure the selected plug and abandonment (P&A) technology is deployed in strict accordance with the approved operational procedures. All necessary downhole checks and tests that could not be performed topside should be completed to verify functionality and barrier placement. Operational parameters must be continuously monitored throughout the deployment to ensure performance within design limits. Full adherence to safety protocols and procedures is critical to maintain control and protect personnel and equipment during execution.

### Quality Control and Verification
Effective quality control and verification during deployment involves continuous real-time monitoring and data acquisition to ensure the operation proceeds within defined parameters. Critical to this process is the confirmation of the barrier setting signature and duration, where measurable, to validate proper placement. It is important to define the expected signature during qualification, such that this can be used as a baseline during deployment. Quality checks should then be conducted at key stages throughout the deployment to promptly identify and address any deviations. Post-deployment, verification of the plug's placement and integrity is performed using methods such as pressure testing, tagging, and logging, strictly following established verification procedures, developed during design and qualification. Additionally, inspection of the recovered toolstring provides further assurance of successful operation. Clarity on requirements and expectations should be captured within the Requirements Proforma, and confirmation of completion within the Deployment Checklist. Comprehensive documentation of all activities, observations, and job execution details ensures traceability and supports operational accountability.



### Waste Management
Proper handling and disposal of all waste materials generated during the deployment process should be defined in the Requirements proforma, and confirmed in the Deployment Checklist, to demonstrate that these are strictly adhered to in compliance with applicable regulations and environmental standards. All waste streams should be accurately tracked and documented to ensure accountability, facilitate reporting, and support sustainable operational practices.

### Post-Deployment and Reporting

This phase focuses on verifying the effectiveness of well isolation through comprehensive testing and monitoring, followed by site restoration to agreed standards. Detailed final reports document all activities, results, and lessons learned, while ensuring regulatory compliance. Clear communication of outcomes to stakeholders completes the process, supporting transparency and accountability.

### Well Isolation Verification
Ensuring effective well isolation is a critical step following barrier deployment. This involves confirming well integrity by comparing pre- and post-installation data through methods such as monitoring surface casing pressure (SCP) and acoustic signals. Additional verification techniques, including logging or other advanced methods, are employed as required to assess the quality of the isolation. Extended leak or pressure testing, using tools like tracers or wireless pressure gauges, provides further assurance by continuously monitoring the barrier's performance over time to detect any potential integrity issues. These requirements for well isolation verification should be incorporated into the Requirements Proforma and compliance with the requirements checked off on the Deployment Checklist.

### Site Restoration
Following the completion of operations, all equipment and materials must be carefully removed from the well site to ensure a clean and safe environment. The site should then be remediated and restored to the agreed upon condition, complying with environmental standards and stakeholder requirements to minimise any lasting impact. Any specific ,requirements for site restoration should be incorporated into the Requirements Proforma and compliance with the requirements checked off on the Deployment Checklist.

### Final Reporting and Documentation
The Deployment Checklist template requires that a comprehensive post-operation report must be prepared, detailing all activities performed, results obtained, and any deviations from the original plan. This includes submission of as-built diagrams and detailed data logs, along with a comparison of monitored parameters against expected or simulated values to evaluate performance. The report should also capture lessons learned and recommendations to improve future operations. Finally, all necessary reports must be compiled and submitted to ensure full compliance with applicable standards and regulatory requirements.

### Stakeholder Communication
Clear and timely communication of the final results and successful completion of the plug and abandonment (P&A) operation should be provided to all relevant stakeholders. Including this within the Deployment Checklist ensures transparency, supports regulatory compliance, and demonstrates collaboration among parties involved.

## A 4.2.3 Qualification Status

This phase ensures that the selected technology is suitable for the intended application by confirming its application envelope within the Requirements Proforma, maturity level within the TRL assessment worksheet, and qualification status as a result of identified qualification gaps. The FMECA template enables a thorough risk assessment to be conducted to evaluate potential failure modes, and all qualification actions and mitigations must be completed and in place. This process provides assurance that the technology meets performance, reliability, and safety requirements for its use as a well barrier element.

### Review Application Envelope and Qualification Status
The technology's application envelope must be defined in the Requirements Proforma and reviewed to confirm its suitability for the intended use, ensuring it aligns with the specific operational and environmental conditions. The Deployment Checklist should confirm that the qualification status should be current and supported by the latest available evidence, reflecting any updates based on recent deployments, testing, or performance data.

### Technology Maturity and Readiness

The maturity of the technology must be clearly defined, and it is suggested to use Technology Readiness Level (TRL) template for this. The TRL should meet or exceed the minimum threshold accepted by the Operator for use in the desired application (defined in the Requirements Proforma) – whether that be a pilot, field trial and actual field use. If the intended deployment is on the Norwegian continental shelf, then under NORSOK D-010 standards, a Well Barrier Element Acceptance Criteria (EAC) table shall be available to document how the technology satisfies specific requirements as an accepted well barrier element.

### Technology Risk Assessment

The Deployment Checklist should confirm that a formal technology risk assessment, such as a Failure Modes, Effects, and Criticality Analysis (FMECA) or equivalent threat assessment, must be completed and reviewed for relevance to the current application. The FMECA template provided in this Framework provides an adapted structure focussed on qualification of well barrier technologies. This assessment should identify and evaluate potential failure modes during the installation process and considers their likelihood and impact. Understanding these risks enables better planning and informed decision-making during execution.

### Qualification Actions and Mitigations

The Deployment Checklist should be used to confirm that all outstanding qualification actions identified during prior deployment or test phases should be fully completed before field use. Furthermore, all risk mitigation measures should be clearly defined, understood, and appropriately implemented for the specific application. This ensures that residual risks are reduced to acceptable levels and that the technology performs reliably within its intended use application envelope.

### A 4.2.4 Additional Technology Specific Checks

While the Deployment Checklist is fully editable, this section provides space to capture considerations specific to the technology, deployment process, and intended application. Additional checklist items may be added here or integrated into the existing phases and sections. Notably, any risk mitigations identified during the FMECA that are relevant to the deployment of the alternative well barrier should be included as distinct checklist items. This ensures that all necessary mitigation actions are executed during deployment, helping to reduce residual risks to as low as reasonably practicable.





Net Zero Technology Centre

Technology Driving Transition

© 2025 Net Zero Technology Centre

**Contact number:**
+44 (0)1224 063200

**Media enquiries:**
pressoffice@netzerotc.com

Net Zero Technology Centre
20 Queens Road, Aberdeen AB15 4ZT

**www.netzerotc.com**