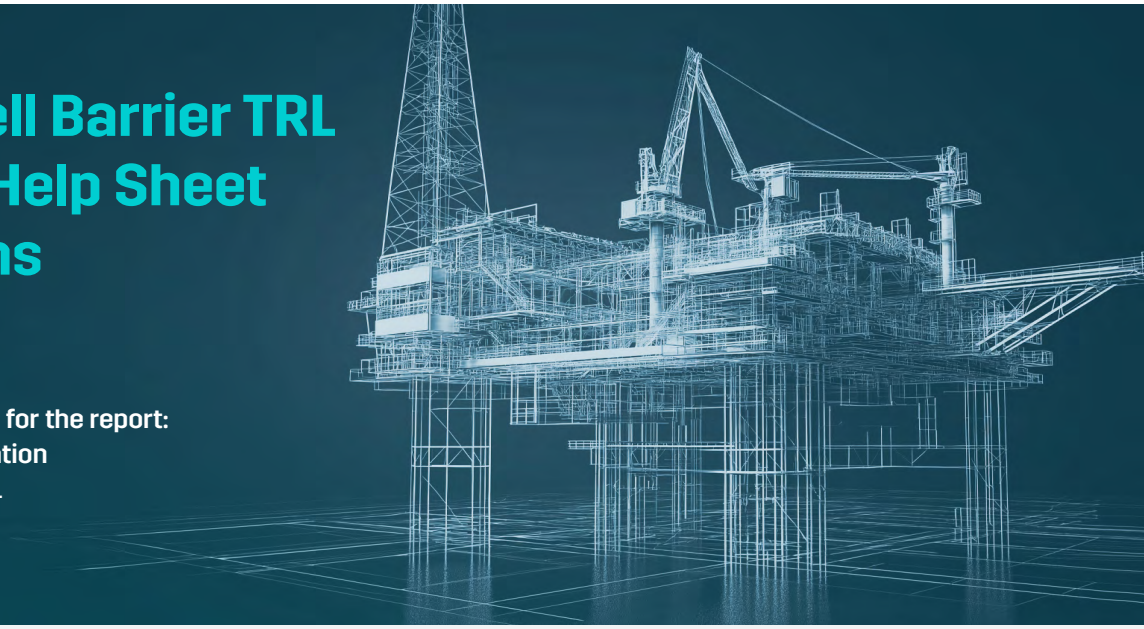
High Level Well Barrier TRL Assessment Help Sheet and Definitions



This is a supporting document for the report:
Well P&A Technology Qualification Framework Guidance – Issue 1

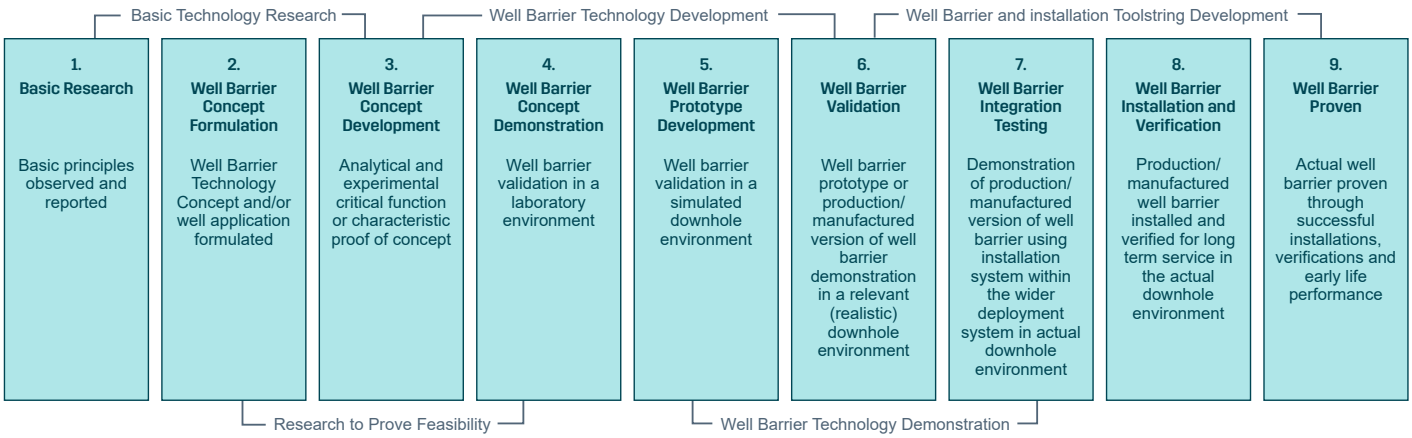
The Technology Readiness Level (TRL) concept, first developed by NASA, is now used in many industry sectors and provides an indication of technology maturity. TRLs typically run from 1 to 9 with TRL 1 being the lowest level of technology maturity and TRL 9 corresponding to field or mission proven technology.

Use of Technology Readiness Levels (TRLs)

Bespoke TRL definitions have been developed, as part of the NZTC technology qualification framework, for alternative well barriers. The intent of the adaptation is to remain consistent with most sectors using the same 1 to 9 levels with slight variations in the TRL descriptions to reflect this specific application (barriers formed in situ and required to function in perpetuity). The high level TRL 1 to 9 definitions provide a common framework for evaluating and communicating technology maturity, e.g. to investors, funding bodies or end-users, to support understanding of the extent and nature of work required to qualify technology to the required level as well as the potential level of technical and commercial risk.

The oil and gas industry also uses a 0 to 7 scale, particularly for subsea applications, see API RP 17Q and ISO 20815. This uses similar definitions for corresponding levels with e.g. API RP 17Q TRL 7 corresponding to NASA TRL 9. It is important to be clear which scale is used (1 to 9) or (0 to 7) when communicating achieved TRL to a third party.

Achievement of a specific TRL may be a requirement for investment or technology application by end-users. TRL milestones are sometimes used as decision stage gates in technology development projects for example to support continued investment decisions, or adoption into deployment projects.



Assessing TRL

Early in a technology qualification project, TRL is often assessed at a high level for the technology system as a whole to enable an initial understanding of the technology maturity to support qualification planning and include in funding applications. The “High Level TRL Assessment” worksheet has been designed to support this. It utilises a bespoke 1 to 9 TRL scale combining guidance from different industry sectors and applied to alternative well barriers. For each TRL, five contributing criteria are described to indicate the type of activities expected to be completed to achieve that TRL.

As work progresses and more detail about the design becomes available, a more detailed sub-system / component level assessment can be undertaken. The sub-system / component assessment can then be also used to provide a more rigorous assessment of an overall technology system TRL.

The TRL assessment should be based on evidence of undertaking the required qualification activity elements to achieve each TRL. It is recommended that the assessment is undertaken as a group activity involving relevant members of the technology development team. For modified technology being qualified for new applications, it can be useful to get input from previous qualification/use. As the assessment can be subjective, the end user may need to be involved in the assessment to ensure there is agreement of achieved TRL.

Using the High Level Well Barrier TRL Assessment worksheet

At the top of the “High Level Well Barrier TRL Assessment” worksheet, the “TRL Assessment Completion Status” will initially be set to “Not started”. Use the dropdown list to change this to “In progress” or “Completed” as appropriate. The “Type of Assessment” in relation to the overall qualification programme should then be identified – this can be set to “Initial”, “Interim” or “Final” to enable the initial TRL at the start of the qualification work to be captured separately to both the current TRL (at a specific interim point in the project) and the final achieved TRL at the end of the qualification programme. The date of each assessment should also be identified.

Populate the “High Level TRL Assessment” table starting with TRL 1. Work across the TRL 1 row from left to right and, for each of the 5 contributing elements consider the work done to date and supporting evidence to assess the extent to which the contributing element has been completed. Use the drop-down list in the cell to the right of each contributing element to identify whether work for that element still has “Not started”, is “In progress”, or has been “Completed”.

The “Summary of evidence” cell under each TRL criterion assessment should be used to capture document references related to the evidence obtained from that criterion and explain the responses including justification of elements marked as “Completed”. Continue working down the table for each TRL until all qualification work to date has been captured.

For some alternative well barrier technologies/applications (e.g. novel process) the element descriptions may need to be adapted for the specific technology/application. Where this is the case, justification should be provided for these adaptions in the “Summary of evidence” cell. Where activities that are not required because they have already been previously undertaken (e.g. material specimen testing for well understood materials) – these should be marked as “Completed”, and justification provided.

The dashboard at the top of the worksheet automatically captures the progress against each TRL as follows:

- **Green TRL:** All contributing elements complete for TRL achievement
- **Yellow TRL:** Work for achievement of TRL still in progress
- **Red TRL:** Work towards achievement of TRL not yet started

The overall TRL is then based on the highest TRL that has all contributing elements completed both for that TRL and all lower TRLs. Any elements identified as “N/A” are excluded from the dashboard analysis.

Using the High Level TRL Assessment for sub-system assessment

While the High Level TRL assessment is designed to evaluate the overarching barrier system's readiness. 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.

Alternatively, it is entirely possible (and even recommended) that the TRL assessment sheet be duplicated and completed separately for different subsystems.

Updating the TRL Assessment

Once the initial assessment is complete, it is recommended that the TRL assessment is updated at a more detailed subsystem / component level assessment to support qualification planning once sufficient design detail is available. This can be recorded line-by-line within the FMECA worksheet. It is also recommended that the assessment is updated at key project decision gates (Current and Interim TRLs) and at completion of technology qualification (Final TRL). Updated assessments can be created and documented using the revision control sheet. For additional information related to the evidence to claim TRL 9, see Appendix 3 of the NZTC Technology Qualification Framework for Well P&A Technologies - Guidance Document.

Modified Technology

When dealing with a new version of a previously qualified technology, the first step is to update the requirements proforma. This document should be revised to reflect the specific needs and operational context for the modified technology, whether it's a change in size, material, or application. This is a critical step because it establishes the new baseline against which the technology readiness and qualification gap assessment will be undertaken.

Once the requirements are clearly defined, the Technology Readiness Level (TRL) assessment can be conducted. In addition to documenting the evidence for the completed application relevant qualification activities, this assessment can then focus specifically on the qualification gaps created by the changes.

By identifying these gaps, the technology developer and operator end user can develop a clear plan to validate the new version/ application of the technology, avoiding the need to re-qualify aspects of the technology that remain unchanged. This streamlined approach ensures that the modified technology meets all necessary standards efficiently and effectively.

TRL High Level Descriptions

Basic Technology Research	1	Basic Research	Basic principles observed and reported
	2	Well Barrier Concept Formulation	Well Barrier Technology Concept and/or well application formulated
Well Barrier Technology Development	3	Well Barrier Concept Development	Analytical and experimental critical function or characteristic proof of concept
	4	Well Barrier Concept Demonstration	Well barrier validation in a laboratory environment
	5	Well Barrier Prototype Development	Well barrier validation in a simulated downhole environment
Well Barrier and installation Toolstring Development	6	Well Barrier Validation	Well barrier prototype or production/ manufactured version of well barrier demonstration in a relevant (realistic) downhole environment
	7	Well Barrier Integration Testing	Demonstration of production/ manufactured version of well barrier using installation system within the wider deployment system in actual downhole environment
	8	Well Barrier Installation and Verification	Production/ manufactured well barrier installed and verified for long term service in the actual downhole environment
	9	Well Barrier Proven	Actual well barrier proven through successful installations, verifications and early life performance

Research to Prove Feasibility

Well Barrier Technology Demonstration



TRL 1
Basic Research

Lowest level of technology readiness with no design history

Translation of scientific research to applied R&D

Research begins with activities to support identification, observation and reporting of basic scientific / engineering principles. Examples might include paper studies of a well barrier's basic properties. Analysis and testing is not expected at this stage.

1. Fundamental well barrier objectives and requirements identified
2. Paper based R&D conceptual studies and research reviews conducted
3. Basic well barrier form (e.g. shape, dimensions, intended well barrier interfaces, etc) and function sketched out
4. Fundamental scientific/engineering principles and properties established
5. Estimates and back-of-the-envelope calculations created to support innovation

TRL 2
Well Barrier Concept Formulation

Basic research has been completed and meets the requirements of TRL 1.

Invention begins. Once basic principles are observed, the well barrier concept and/or application is formulated. Well barrier types and applications are speculative and involve essentially a paper/analytical study not involving physical models. No previous design history assumed for a relevant or similar alternative well barrier.

1. Research extended to formulate well barrier concept
2. Potential well application and barrier type identified
3. Functionality investigated by analysis / engineering calculations
4. Preliminary proposals of fit (Well barrier element interfaces, etc.) of well barrier with preliminary engineering drawings / diagrams created to communicate concept.
5. Manufacturing and installation methods / principles explored

TRL 3
Well Barrier Concept Development

Concept formulation has been completed and meets the requirements of TRL 2.

Active research and development is initiated. This includes analytical studies and small scale laboratory R&D experimentation to physically prove well barrier concept and functionality of separate elements and interfaces of the well barrier.

1. Well application objectives / goals defined
2. Analytical studies to support and / or investigate feasibility of identified well barrier applications
3. R&D experimentation undertaken to measure parameters of interest (e.g. permeability, sealing, strength etc) and compare with analytical predictions to prove elements of functionality.
4. Conceptual engineering drawings created to show form, fit (including the installation system/toolstring concepts) and function. Specifications created to outline installation process, installation system/ toolstring concept, well barrier element interfaces and function.
5. Some engineering calculations undertaken to confirm form, fit (including installation system/ toolstring concept) and function.

TRL 4
Well Barrier Concept Demonstration

Concept development has been completed and meets the requirements of TRL 3.

Alternative well barrier material and components are integrated into a small (e.g. 2-inch plug), lab-scale physical model and functionally tested in a laboratory environment to establish that they will work together. This is relatively “low fidelity” compared to the eventual well barrier envelope. Material(s) testing and reliability testing are performed on key well barrier elements, and toolstring components, in a testing laboratory prior to prototype construction.

1. Physical models involving integrated well barrier elements / small lab-scale plug tests undertaken to demonstrate functionality.
2. Requirements and operability limits are identified. Requirements proforma is completed. Analysis of potential failure modes and mechanisms initiated (e.g. Qualification-FMECA). This should consider the installation, long-term integrity and verification of the well barrier.
3. Laboratory scale material testing of lifecycle associated degradation mechanisms (e.g. corrosion, creep, ageing etc) undertaken.
4. Integrity and reliability drivers of well barrier system identified together with integrity / reliability goals for key elements. Identification of analysis methods for Well Barrier System reliability / integrity, likelihood and consequence assessments.
5. Feasibility of well barrier manufacture / assembly / transit / storage assessed. Feasibility of installation methodology, process and installation system / toolstring concept assessed.

TRL 5
Well Barrier Prototype Development

Concept demonstration has been completed and meets the requirements of TRL 4.

The alternative well barrier material and components/elements are installed within a downhole environment which is reasonably representative of the intended well architecture (e.g. casing, annulus cement etc) to form a prototype, so it can be tested in simulated downhole conditions including functional, performance and reliability tests without integration into a broader system (such as installation equipment and an actual well). The prototype should be representative of eventual scale but does not necessarily need to be full-scale.

1. Physical prototype constructed to demonstrate form, fit and functional performance.
2. Functional performance, durability and life tests undertaken to confirm performance, reliability, operating/ destruct limits and degradation rates/ limits as acceptable based on the requirements and limits identified within the FMECA and Requirements Proforma
3. All analysis completed for the Well Barrier System which may consist of multiple well barrier elements and interfaces and based on test data. Analysis methods may include FEA, engineering calculations, and reliability (RBD, FTA etc) and consequence analysis (e.g. QRA)
4. Required installation & well barrier integrity monitoring defined.
5. Risks from well barrier manufacture / assembly / transit storage / installation, identified and addressed. Risks from deployment / installation identified and addressed. Potential forhuman error addressed.

TRL 6
Well Barrier Validation

Prototype development has been completed and meets the requirements of TRL 5.

Alternative well barrier material is specified and produced to specification, well barrier components built and assembled as a manufactured unit (or full scale prototype) and put through its qualification program in a simulated downhole environment (e.g. pressurised plug test chamber, test well etc.). Reliability testing limited to demonstrating that functional and performance criteria can be met in the intended operating and environmental condition, as far as practical. The installation process should represent but may not fully replicate the intended process for installing the well barrier into an actual well.

1. Production specification of alternative well barrier materials and manufacturing specification for well barrier components created.
2. Technical risk assessment (e.g. FMECA) updated to reflect product manufacture / assembly / transit / storage and delivery.
3. Produced alternative well barrier material and manufactured well barrier components (or prototype) tested in simulated or intended downhole environment to confirm function / performance within acceptable limits.
4. Installed well barrier monitoring data collection process established. Requirements for verification testing established for well barrier installed in a pilot well.
5. Required acceptance testing of alternative well barrier material / well barrier component production/ manufacture/ assembly is defined (e.g. composition checks, tolerances). Production/ manufacturing / assembly testing process demonstrated to detect and correct / remove defective well barrier materials, components. Installation process demonstrated to be feasible.

TRL 7
Well Barrier Integration Testing

Well Barrier validation has been completed and meets the requirements of TRL 6.

Production / manufactured version of well barrier integrated with intended installation system, and installed with full interface and functional test in a pilot well/field test. For some technologies, this may be outside the intended field/offshore environment.

1. Technical risk assessment (e.g. FMECA) updated to ensure interfaces with the installation system and well are addressed. The consequence assessment should consider risk to people and the environment, either within the FMECA, or an alternative safety risk assessment e.g. HAZOP.
2. Function / performance tested when installed with the intended installation system / toolstring (as far as is possible), within representative well and well barrier envelope - not necessarily in intended downhole environment.
3. Well barrier, installation process, installation system / toolstring, verification systems and any interfaces addressed to confirm well barrier does not impact integrity of the well and that the well does not impact integrity of the well barrier.
4. Well barrier integrity / reliability data collection initiated. Validation of verification method for actual installed well barrier. Justification prepared for early-life monitoring duration (to achieve TRL 8) and required number and minimum duration of successfully installed well barriers (to achieve TRL 9)
5. Demonstration that the well barrier material / well barrier component meet the requirements in pilot well. Installation system/toolstring and installation process demonstrated in pilot well

TRL 8
Well Barrier Installation and Verification

Well barrier integration testing has been completed and meets the requirements of TRL 7.

Production/ manufactured version of well barrier successfully installed and verified in a well in the intended field/offshore environment. Extended monitoring after installation and verification may be used to verify early life well barrier integrity. Monitoring duration may vary, but should be as long as practically feasible (e.g. maximised as part of the overall well decommissioning campaign). Failed installations need to be investigated and successfully rectified with improvements implemented.

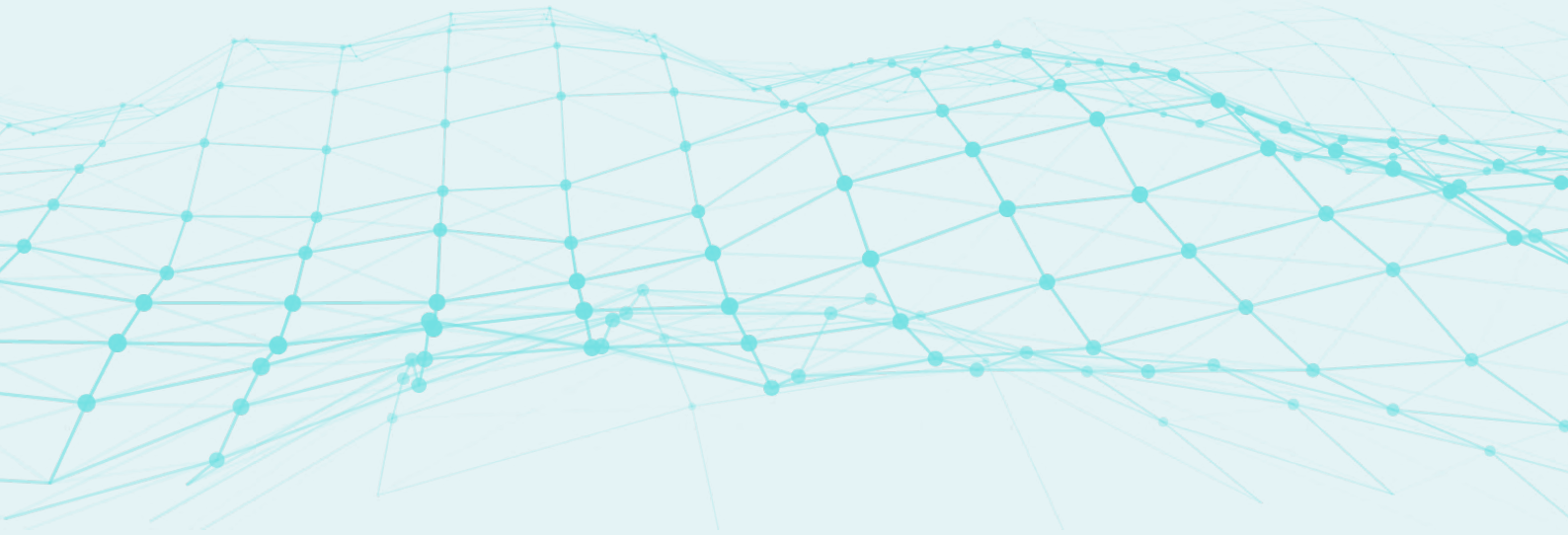
1. Technical risk assessment (e.g. FMECA) updated to ensure installation / deployment / verification risks addressed and actions implemented.
2. Well barrier installation / testing / verification undertaken with actual installation system / toolstring and within actual well architecture and downhole conditions. Investigation and improvements undertaken for failed / underperforming installation and verification activities, or early life integrity issues.
3. Any remaining interface / function qualification completed that could not be done before start of deployment (e.g. testing with actual fluids or environmental loads, pressure control equipment).
4. Detailed installation checklist and verification defined and completed. Well barrier verified.
5. Confirmation that well barrier is able to work as intended. Well barrier integrity demonstrated through early life monitoring. Integrity/reliability not compromised by installation/deployment/ verification process.

TRL 9
Well Barrier Proven

Well barrier installation, testing and verification has been completed and meets the requirements of TRL 8.

Actual application of the well barrier technology in its final form and under normal operating conditions, for a representative length of time to demonstrate achievement of early life and through life reliability and integrity goals and requirements. Appropriate justification should be prepared to support the defined sufficient length of time, which will be dependant on the type of technology, the application and expected life.

1. Early life well barrier integrity demonstrated to performance requirements for defined number and minimum duration for successfully installed well barriers.
2. Well barrier, installation and verification performance data collected and analysed to demonstrate a successful track record of deployments.
3. Technical risk assessment (e.g. FMECA) updated with post installation and verification of well barrier and life cycle risk management.
4. Design, functionality and reliability improvements achieved through implementation of identified modifications for subsequent well barrier deployment.
5. Evidence collated that well barrier functions in downhole environment with required integrity / reliability





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Technology Driving Transition

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