NOPSEMA
Australia's offshore energy regulator

GUIDANCE NOTE

Hazard identification and risk assessment

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Core concepts

- The aim of a robust hazard identification process is to ensure that the titleholder knows about existing well integrity hazards and the associated risks which could lead to a loss of integrity of the well.
- Once well integrity hazards have been identified and the risk has been assessed, the titleholder will be able to take action to properly manage the risks.
- It is important to choose a hazard identification technique(s) and risk assessment methodology which provides an adequate depth of analysis.
- Hazard identification provides a basis for identifying, evaluating, defining and justifying the selection (and rejection) of control measures for reducing risk.
- Hazard identification should provide sufficient knowledge, awareness and understanding of the well integrity hazards that could lead to a well blowout to be able to prevent and mitigate undesirable outcomes.
- Identified well integrity hazards should not be ignored or discounted simply because control measures are, or will be, in place.
- The full range of well integrity hazards and event types should be considered and the outputs of the hazard identification and risk assessment processes documented.
- The well hazard identification process should consider all operating modes and activities that are expected to occur.
- The well integrity risk assessment process should recognise that combinations of failures can occur, even though these may appear highly unlikely.
- The well integrity hazard identification and risk assessment processes should be ongoing and dynamic.
- The well integrity hazard identification and risk assessment processes should be utilised during the Management of Change (MoC) process to identify additional hazards or increased risk.

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Abbreviations/acronyms

ALARP	As low as reasonably practicable
HAZID	Hazard identification
HAZOP	Hazard and operability
MoC	Management of change
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority

Key definitions

The following are some useful definitions for terms used in this guidance note. They are a suggested starting point only and are not prescriptively defined.

Regulations	means the Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011
Well integrity	integrity, in relation to a well, means the capacity of the well to contain petroleum, a greenhouse gas substance, or any other substance.
ALARP	a term used to identify a risk that has been reduced to a level that is 'as low as reasonably practicable'. In practice this means a titleholder must demonstrate through reasoned and supported arguments that there are no other practicable options that could reasonably be adopted to reduce risks further.
Control measure	is any system, procedure, process, device or other means of eliminating, preventing, reducing or mitigating the risk of well integrity failure arising at or near a well. Control measures are the means by which risk to well integrity is eliminated or minimised. Controls can take many forms, including physical equipment, process control systems, management processes, operating or maintenance procedures, well control contingency plans, and key personnel and their actions.
Risk assessment	is the process of estimating the likelihood of an occurrence of specific consequences (undesirable events) of a given severity.
Similar risk	NOPSEMA considers "risks to the integrity of each well are similar" to mean similar geological structures, pressure gradients and fracture gradient.
Qualitative risk assessment	can be used where the determination of both consequences and likelihood of event occurrence is largely based on the judgement of qualified and competent personnel, based on their experience.
Quantitative risk assessment	is another technique that can be applied to assess well integrity risks. This technique also assesses both consequences and probability, but uses information from databases on well integrity failures to quantify the probability of an event occurring
Performance standard	means a standard established by the titleholder of the performance required for a system, item of equipment, person or procedure which is used as a basis for managing (controlling) the risk of a well integrity failure.

Failure-mode and effects and criticality analysis (FMECA)	can also be used to determine well integrity risks. FMECA is particularly useful in establishing the types of component failure that can occur, the effect on the well barrier and the likelihood of such failures occurring. This information can then be used to assist design improvements and to establish the type and frequency of monitoring, surveillance and maintenance required to reduce the risk of the failure modes identified as part of the FMECA.

1. General

The titleholder shall identify the well integrity hazards and assess the associated risks over the lifecycle of the well. Risk is defined by the likelihood of event occurrence and the consequences should the event occur. The titleholder should determine the acceptable risk level including the definitions for likelihood and consequences of event occurrence. During the management of change (MoC) process any additional introduced hazards or changes to risk can be identified using the hazard identification and risk assessment techniques.

The Australian/New Zealand standard on risk management AS/NZS ISO 31000:2009 provides a generic framework for establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk. Detailed risk assessment methods and techniques can also be found in ISO 17776 and ISO/IEC 31010.

The following regulations describe where risk assessments are required:

Part 5: Criteria for acceptance of well operations management plan

Reg 5.08 (d)	For regulation 5.07, the criteria for acceptance of a well operations management plan for a well are: that the plan demonstrates how the risks to the integrity of the well will be reduced to as low as reasonably practicable.

Part 5: Contents of well operations management plan

Reg 5.09 (1) The matters that must be included in a well operations management plan are the following:

(b) a description of the risk management process used to identify and assess risks to the integrity of the well.

(c) a description and explanation of the design, construction, operation and management of the well, and conduct of well activities, showing how risks to the integrity of the well will be reduced to as low as reasonably practicable.

(e) a description of the control measures that will be in place to ensure that risks to the integrity of the well will be reduced to as low as reasonably practicable throughout the life of the well, including periods when the well is not operational but has not been permanently abandoned.

(i) a description of the arrangements that will be in place for suspension and abandonment of the well, showing:

(i) how, during the process of suspending or abandoning the well, risks to the integrity of the well will be reduced to as low as reasonably practicable; and

(ii) how the actions taken during that process will ensure that the integrity of the well is maintained while the well is suspended or abandoned.

2. Risk assessment considerations of well integrity management

2.1. General

This section discusses how risk assessment techniques are used as a tool to assist in the management of well integrity. It identifies factors that should be considered and introduces evaluations that may be applied when using risk assessment for:

- monitoring, surveillance and maintenance regimes for well barrier elements
- determining which of the barrier elements are considered safety-critical elements that require performance standards and assurance tasks that confirm compliance to the performance standard
- determining appropriate courses of action to address problems encountered during these monitoring, surveillance and maintenance regimes
- establishing the risk of loss of containment for various well types.

The techniques that can be applied for risk assessments are numerous and varied. The assessment of a well integrity-related event can be depicted on a risk assessment matrix such that risk can be categorised or ranked based on the combined effects of consequence and likelihood of event occurrence.

Once the risk level is determined, ALARP principles can be used to determine whether further controls or mitigations are required to reduce the level of risk (refer to guidance note "ALARP in the context of well integrity" - GN1616).

2.2. Risk assessment of subsurface conditions

During the well design phase a risk assessment of the subsurface conditions must be undertaken. A multidisciplinary team should undertake this assessment (e.g. geologists, geophysicists, reservoir and drilling/completions and production engineers). This assessment underpins the design criteria for material selection for the construction and production of the well. For integrity purposes, the assessment should include:

- the purpose of well (e.g. exploration, appraisal, development)
- a full geological prognosis
- the depths and formation types of potential hydrocarbon-bearing zones
- the types of hydrocarbons expected (e.g. oil or gas)
- the potential for hazardous chemicals in well fluids (e.g. H2S, CO2 etc.)
- the potential for hazardous formations (e.g. salt, reactive clays, faults)
- an estimate of potential overpressure (depth and intensity)
- an estimate of temperature of the well
- an estimate of fracture gradient and potential lost circulation zones
- a shallow gas assessment (gas and shallow water flows).

Inputs to the risk assessment should include:

- output from seismic surveys and interpretations
- deep (exploration) seismic
- shallow (site survey) seismic
- geological review of the basin, area and well
- offset well review.

2.3. Well design review

The well basis of design should be peer reviewed by engineers not involved with the design of the well, such as partner personnel, service company specialists, drilling contractors and/or external experts. The objectives of this review should include to:

- challenge the well design and compare it with the stated objectives
- review the pore pressure, fracture gradient estimate
- review planned operations.

It is important that the well engineers concentrate on operational detail, and that the planning team justify their design and the measures required to reduce the risks to ALARP.

Other data sources should be reviewed to identify well hazards. These include, for example:

- offset well reports (for all risks and operations problems)
- site survey (for seabed conditions)
- metocean reports (weather and environmental conditions)
- platform or project HAZIDs/HAZOPs for relevant wells.

The results of these assessments should be recorded in the form of a risk register which may also note mitigation and closeout of items.

For re-entry of side-track wells, the records of the existing well (e.g. construction, operation, intervention, suspension) should be reviewed.

2.4. Risk assessment in the operational phase considerations

When assessing risks associated with well integrity in the operational phase, well location risks should be considered, including:

- geographical locations (remote, cyclone area, deepwater etc.)
- well type (platform, subsea, manned or unmanned facility)
- exploration / appraisal well, platform wells, subsea template or clusters.

The following should also be considered:

- the proximity of the well to personnel and the potential effects on health and safety if there is a failure of well integrity
- the proximity of the well to the environment and the potential effects on the environment if there is a failure of well integrity
- the proximity of the well to other wells and infrastructure and the potential effects on these if there is a failure of well integrity
- the ability to access the well in order to:
    - monitor its condition
    - perform maintenance
    - perform repairs
    - perform well kill operations

- the ability to access the area in the vicinity of the well in order to mitigate the effects of any potential loss of integrity
- the ability and time to drill a relief well or perform cap and contain operations, if required.

2.5. The potential of the well to flow

The ability of the well fluids to flow to the surface or into an undesirable subsurface location within the wellbore (cross-flow, underground blowout, fractures, etc.), potentially has a bearing on the magnitude of the consequences associated with a loss of well integrity. Consideration should be given to the impacts of the following:

- potential sources and leak-paths (tubing, annulus, completion equipment)
- failure of other barrier elements
- flow rates, volumes, pressures and temperatures
- duration over which the well is able to sustain flow
- effects from offset wells, e.g. the effect that an offset injection well will have on sustaining the reservoir
- pressure support to a producer that will enhance its ability to flow.

2.6. Well formation fluid constituents

The composition of the well formation fluids may cause failure of well barriers due its corrosive/erosive effects. The risk of personnel exposure to toxic or carcinogenic substances, as well as the flammable and explosive nature of the potential leaking fluids, must be factored into the risk assessment. The following should be considered:

- sour components
- corrosive or toxic components
- flammable or explosive components
- erosive components
- compatibility between components
- formation of emulsion, scale, wax and hydrate deposits.

2.7. External risk consideration

In addition to well integrity risks influenced by well formation fluids, there are potential well integrity risks posed by exposure of well barriers to external environments that can be unrelated to the production or injection intervals to which these wells are connected. The following effects should be considered:

- external corrosion of structural components such as conductor casing, surface casing and wellhead exposed to the atmosphere (e.g. due exposure to weather) or to the marine environment

- external corrosion of casing strings exposed to corrosive fluids in subsurface locations (e.g. aquifers containing corrosive fluids, incompatibility between annulus fluid and top up fluid, corrosive top up fluid)
- fatigue of structural components due to cyclic loading (e.g. motion of wellheads, conductors, tieback casing strings, etc.) and also as a result of waves and currents offshore, wellhead motion due to interactions between loads imposed by BOPs/risers and wellheads during any drilling or work-over activities)
- impact of cyclic and/or thermal loading of wells on soil strength and the ability of soils to provide structural support to the well
- external loads on wells associated with earth movements (e.g. reservoir compaction, earthquakes, tectonic motion associated with faults and motion of ductile materials such as salt formations)
- mechanical impacts associated with dropped objects (from facilities, vessels, vehicles or other equipment in the proximity of the wells)
- mechanical impacts associated with collisions (e.g. by ships).

2.8. Redundant systems

Redundant systems constitute the components within the well that provide additional safeguards to mitigate potential impairments to well barrier envelopes. Consideration should be given to the following when assessing how a redundant system affects well integrity risks:

- extent to which the redundant systems can be operated independently of a system that could be impaired
- response time of redundant systems
- service conditions for which the redundant systems are designed, relative to those of the system that can be impaired
- method of operation of the redundant systems, e.g. manual or automatic.

Examples of redundant systems include an outer annulus (if rated), additional inline valves and additional ESD systems.

3. Well integrity risk assessment techniques

Risk assessment techniques are used to assess the magnitude of well integrity risks; whether these are potential risks, based on an assessment of possible failure modes, or actual risks, based on an assessment of an anomaly that has been identified.

Different types of techniques may be applied as deemed appropriate by the titleholder for the particular well integrity issue that it is necessary to assess. A risk assessment process typically involves:

- identification of the types of well anomaly and failure-related events that are possible for the well(s) being assessed
- determination of the potential consequences of each type of well failure-related event (e.g. health, safety, environmental or a combination of these factors)
- determination of the likelihood of occurrence of the event

- determination of the magnitude of the risk of each type of well failure-related event based on the combined effect of consequence and likelihood.

The assessment of any well failure-related event is normally depicted on a risk assessment matrix (see an example of a “5 by 5” matrix in Figure 1) such that risk can be categorised or ranked based on the combined effects of consequence and likelihood of occurrence.

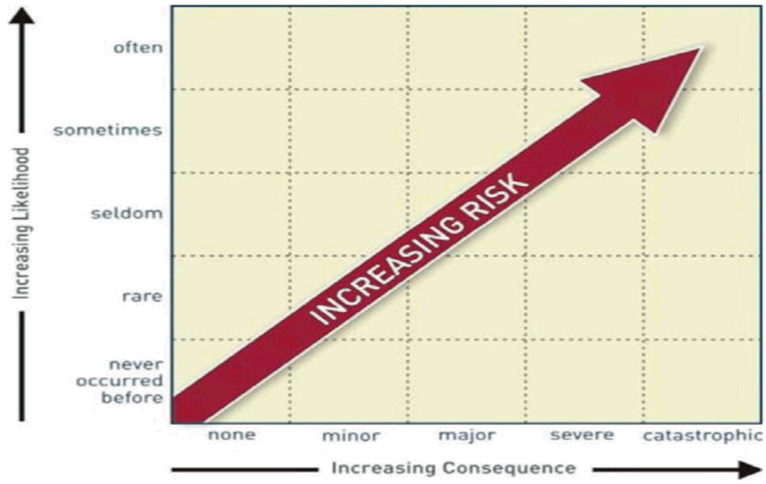

Figure 1 — Example of a risk assessment matrix

The titleholder shall determine:

- appropriate risk levels/definitions for consequence (severity) and likelihood of occurrence (probability) categories on the risk assessment matrix axes; increasing levels of consequence and/or likelihood reflect increasing levels of risk (higher risk rankings)
- appropriate risk levels/definitions for the risk regions (boxes) within the risk assessment matrix.

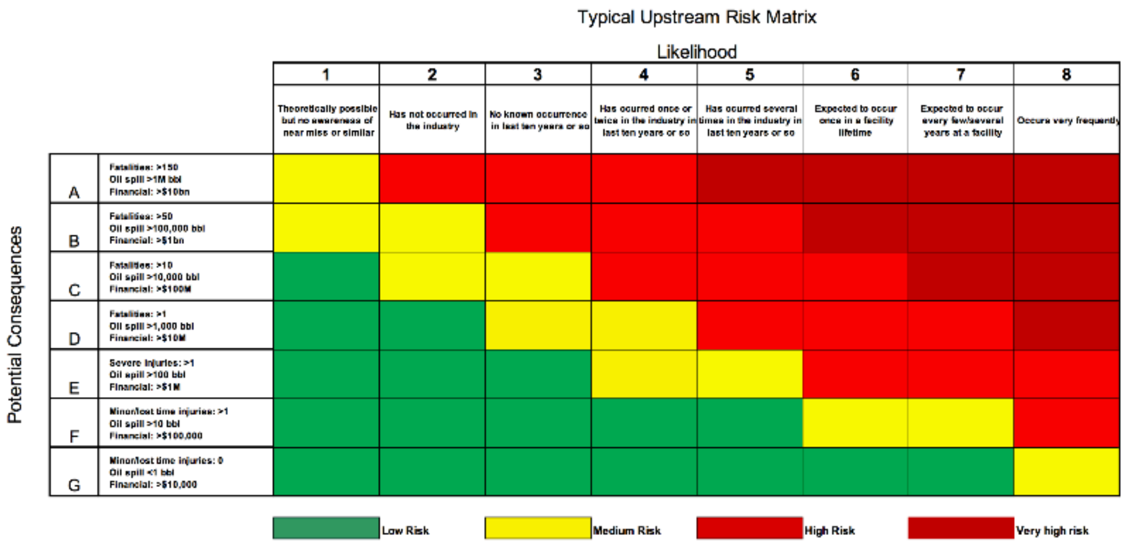

Figure 2 — Example of typical upstream risk matrix

A qualitative risk assessment may be used where the determination of both consequence and likelihood of occurrence is largely based on the judgement and experience of qualified and competent personnel.

Quantitative risk assessment (QRA) is another technique that may be applied to assess well integrity risks. QRA also assesses both consequence and likelihood but uses information from databases on well integrity failures to quantify the probability of a given event occurring.

Failure-mode and effects and criticality analysis (FMECA) can also be used to determine well integrity risks. FMECA is particularly useful in establishing the types of component failures that can occur, the effect on the well barrier envelope(s) and the likelihood of such failures occurring. This information can then be used to assist design improvements and in establishing the type and frequency of monitoring, surveillance and maintenance required to reduce the risk of the failures modes identified as part of the FMECA.

The bow-tie schematic is a useful methodology for identifying and documenting major accident hazard, consequences, barriers (number required, prevention and recovery measures), and escalation factors and controls. The risks associated with identified hazards are mitigated to an acceptable level through imposing barriers.

An example of use of the bow-tie method is illustrated below.

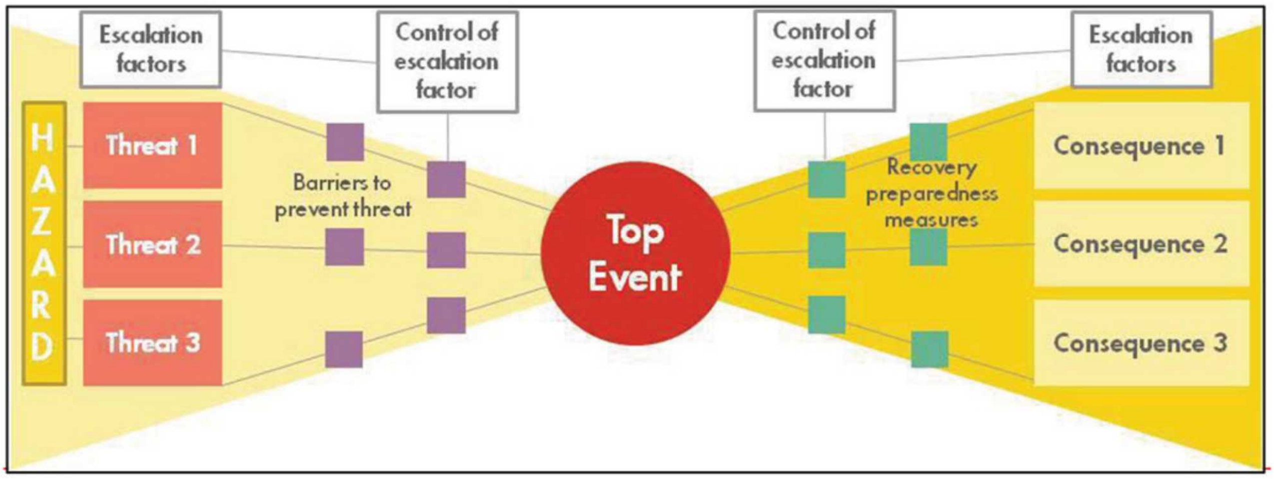

Figure 3 – General example of a bow-tie schematic

3.1. Risk register

The titleholder should establish a risk register for all the risks associated with the identified hazards, which are maintained throughout the well life cycle. The risk register should contain, but not be limited to, the following:

- identified hazards and associated risks
- existing safeguards, mitigations and control measures
- initial risk description (likelihood and consequences)
- plan for implementation of control measures
- description of risk (likelihood and consequences) after application of control measures.

ID	Hazards	Risk Description		Existing safeguards	Risk before mitigation		Risk-mitigating control				Risk after mitigating control		Risk status	Comments
		Causes	Consequences		Prob	Impact	Measures	Status	Responsible	Due date	Prob	Impact		
							...							
1	Tubing to annulus leak	Corrosion due injection water quality out of spec	Loss of primary well barrier	Continous monitoring of injection water quality	P3	I4	Reevaluate material specification to increase operational limits for injection water quality	Proposed	xxx	<dd.mm.yyyy>	P1	I4	Open	
2														
3														

Figure 4 – Example of a risk register

4. Application of risk assessment in establishing monitoring, surveillance and maintenance requirements

Monitoring, surveillance and maintenance techniques for wells have been described earlier. The determination of appropriate techniques, including production monitoring systems, annulus monitoring and the required frequencies at which these techniques are applied, should ideally be supported by an assessment of the well integrity risks.

The risk assessment normally involves following the processes to identify and rank the risks from potential well failure-related events.

The risk assessment is used to help establish:

- types and frequency of monitoring
- types and frequency of surveillance
- types and frequency of maintenance
- appropriate verification test acceptance criteria.

Once these parameters are established, they are used to reduce the risks of the identified potential well integrity failure related events to as low as reasonably practicable (ALARP).

There should be a clear linkage between the overall risk profile of any given well type and its monitoring, surveillance, maintenance and acceptance regime. This normally means that wells with higher risks of well failure related events require more frequent maintenance in order to reduce risk.

It is necessary for the titleholder, when using a risk-based approach to map, for each well type, the components that may require monitoring, surveillance and maintenance in a risk-based model. The risk-based model (see American Petroleum Institute API RP 580 for risk-based inspection examples) is used to identify the magnitude of the risk presented by the failure of a single component (initially assuming no monitoring, surveillance or maintenance) and maps this risk on a risk assessment matrix. Once the risks for all components are mapped on the matrix, isometric lines (i.e. lines plotted on the matrix that represent the same level of risk) can then be used to help define appropriate monitoring, surveillance and maintenance frequencies, together with an acceptance regime for such activities, to prevent and mitigate the identified risks.

4.1. Application of risk assessment in the assessment of well integrity anomalies

If an anomaly has the potential to affect the defined operating limits of the well, the risks posed by such an anomaly should be assessed and addressed. The titleholder may already have established the activities necessary to address the anomaly based on existing practices or procedures.

The following steps describe the typical process that should be followed to establish the well integrity risk:

- identify the well integrity anomaly
- assess whether the anomaly poses potential risks from well failure-related events or can lead to further anomalies that pose such risks
- assess the consequences and likelihood of each risk
- assess the magnitude of each risk (equal to the product of the consequence and the likelihood) associated with each event, preferably using a risk assessment matrix
- assess what actions or activities can be implemented that mitigate or reduce each risk
- assess the consequence, likelihood and magnitude of each risk after implementation of mitigating actions or activities, preferably using a risk assessment matrix
- assess whether each residual risk (i.e. the magnitude of the risk after any risk mitigation/reduction measures are implemented) is as low as reasonably practicable enough to permit the well to remain operational
- maintain reliable records that show the well status.

The magnitude of risk (prior to implementation of any risk reduction measures) should be used in determining the actions that are appropriate to address the anomaly. Generally, the higher the risk the greater the priority and/or resources that are required.

5. Well type risk profile

The risk defined in the risk register of the well or field development plan determines the elements of the well type risk profile for that given asset. The titleholder may have several differing types of wells that are covered by their Well Integrity Management System; well types can include e.g. water injectors, gas producers, disposal wells and oil producers. In such circumstances, especially when developing and operating a field, it can be expedient to develop risk profiles for each well type, taking into consideration well barrier management, well components and valve testing frequency. Consideration should also be given to suspended (a well that is not operational but not yet abandoned) well barrier management and surveillance. The use of such a risk profile allows consistent management of well barriers.

5.1. Well suspension and abandonment

The titleholder should identify the key risk areas for well suspension and abandonment activities, and the preventive controls and mitigation recovery measures that are required to manage the well integrity. The risks should be documented in a risk register and be reviewed with personnel involved with performing the activity.

In planning for well suspension and abandonment activities, the titleholder should clearly identify the following:

a) the integrity objectives of the well suspension or abandonment activity

b) the risks that may threaten achievement of each of the objectives

c) available controls to mitigate such risks.

In identifying and assessing such suspension or abandonment risks and objectives, the titleholder should consider, as a minimum:

- the risks associated with any concurrent activities at the time of well suspension or abandonment
- longer-term well ownership and liability, obligations and risk
- potential future activities at the suspension or abandonment location or adjacent areas (surface and subsurface activities)
- potential changes in reservoir pressure and fluid composition due to future projects or natural processes.

The success of well suspension or a long-term abandonment is dependent on several factors and the design and operational phase must consider the following risks:

- the integrity of the casing, tubing or completion equipment to be left in the well (note: a prudent titleholder is expected to remove all accessible completion tubing and completion equipment that may in future create a leak path due to degradation of the equipment)
- confirmation of the integrity of the cement in place being considered as a barrier behind the casing / liner or previously isolated side-track(s)
- every attempt must be made to restore the cap rock
- the barrier must be designed for seal-ability, place-ability and durability
- realistic formation pressures, temperatures, mechanical stresses and chemicals (note: even though the reservoir has been depleted through production, over time the production formations may return to virgin pressures and temperatures)

- cements must be tested and be designed to prevent shrinkage or expansion, cracking, creep and chemical degradation and be tested for adhesion to the particular tubulars they are to seal
- quality of placement (note: poorly placed cements may contain channels and contamination affecting the cement properties)
- well angle (it becomes more difficult to set a competent isolation cement plug as the well angle increases due to cement channelling)
- geological factors:
  - Have major faults been identified and if they slip what would be the resulting damage to the abandoned well?
  - Could any formations cause damage to the barrier envelope e.g. squeezing salts that could damage cement and casing or shallow water that could induce corrosion?
  - Are there formations that could assist isolation e.g. shales that with time squeeze and assist the sealing process?
  - Have the barriers been placed with due consideration of the pore pressures and fracture gradients?

How have the barriers been tested and verified that they have been appropriately placed? (Note: tagging a cement plug set in tubing with wireline tools is notoriously inaccurate).

6. References, acknowledgements and notes

AS/NZS ISO 31000:2009 Australian/New Zealand Standard "Risk Management – Principles and Guidelines" (AS/NZS ISO 31000:2009)

ISO 17776 International Standard "Petroleum and natural gas industries – Offshore production installations – Guidelines on tools and techniques for hazard identification and risk assessment"

Oil & Gas UK: Well Life Cycle Integrity Guidelines

Oil & Gas UK: Well Decommissioning Guidelines

Oil & Gas UK: Guidelines on qualifications of materials for the abandonment of wells

NORSOK Standard D-010: Well Integrity in Drilling and Well Operations

ISO/DIS 16530, Petroleum & Natural Gas Industries - Well Integrity - Part1: Life Cycle Governance

API Bulletin 97, Well Construction Interface Document Guidelines

UK HSE *Principles and Guidelines to assist HSE in its judgements that duty holders have reduced risk as low as reasonably practicable*

UK HSE *Policy and guidance on reducing risks as low as reasonably practicable in design*

The UK offshore oil and gas industry *guidance on risk-related decision making* (Oil & Gas UK, 2014)

Note: All regulatory references contained within this Guidance Note are from the Commonwealth *Offshore Petroleum and Greenhouse Gas Storage Act 2006* and the associated Commonwealth Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011. For facilities located in Victorian designated coastal waters, please refer to the Victorian *Offshore Petroleum and Greenhouse Gas Storage Act 2010* and the associated Offshore Petroleum and Greenhouse Gas Storage Regulations 2011. For facilities located in other designated coastal waters, please refer to the relevant State or Northern Territory legislation.

For more information regarding this guidance note, please contact NOPSEMA:

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