DNV

VEDLIKEHOLDSSTYRING - KORROSJON UNDER ISOLASJON (KUI)

Ptil - Maintenance management - corrosion under insulation (CUI)

Petroleumstilsynet

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Applicable contract(s) governing the provision of this Report:

Objective:

Review and evaluation of publicly available guidelines and operators' in-house strategies for CUI management.

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0	2021-12-20	First issue, for comment by PSA			
01	2022-01-14	Issue with comments from PSA implemented	FWIG	JVJ	EIKE
02	2022-01-21	Minor update in chapter 2.1	FWIG	JVJ	EIKE

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1 EXECUTIVE SUMMARY

DNV has on behalf of the Petroleum Safety Authority Norway (PSA) reviewed the current industry practice with respect to management of CUI within the oil and gas industry in Norway. The scope of work includes both the review of public available guidelines and operators' in-house strategies for CUI management as well as identification of learning and improvement opportunities. The work has been organised as review of guidelines, questionnaires to operators as well as a workshop with 7 operators on the Norwegian continental shelf.

Norwegian:

DNV har på vegne av Petroleumtilsynet gjennomført oppdraget «Identifisering av KUI-aktiviteter med hensyn til fare og ulykkesrisiko, risikoelementer, kompenserende tiltak og vedlikholdsstyring i petroleumsnæringen». Arbeidsoppgaven har vært å beskrive hvilken praksis som benyttes i næringen og eventuelt hvilke nasjonale og internasjonale standarder den bygger på samt å identifisere læringspunkter på tvers i en samlet næring. Arbeidet har vært gjennomført i form av gjenomgang av retningslinjer, spørreundersøkelser og workshop sammen med 7 operatører.

2 INTRODUCTION

2.1 Background

Corrosion under insulation is one of the major threats to the integrity of process plants in the oil and gas industry. A study performed by PSA indicates that about 50% of the reported hydrocarbon leaks at onshore plants are caused by CUI.

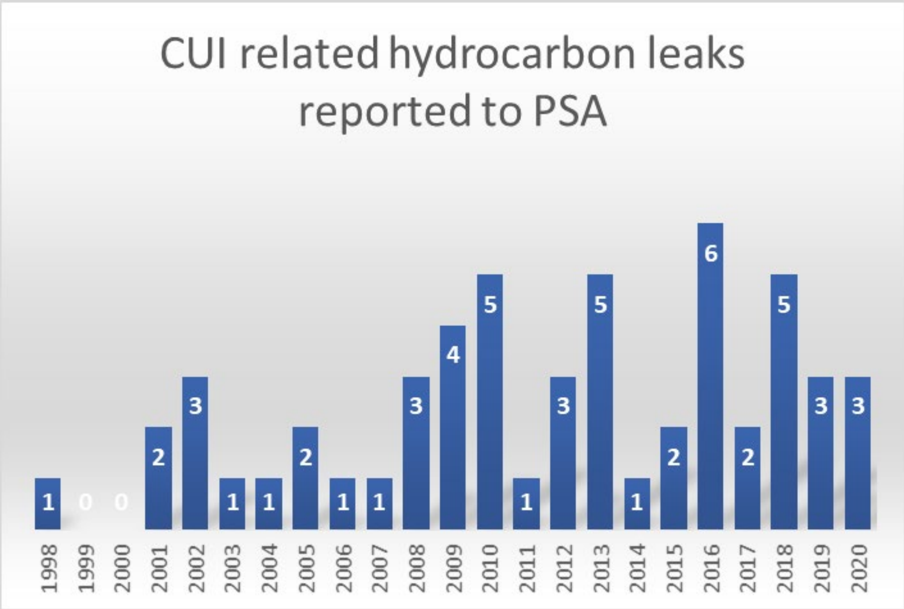


Figure 1 CUI related hydrocarbon leaks reported to PSA.

The figure above gives an overview of the incidents reported to the PSA over the last 23 years. Root cause analysis has identified these leaks to be caused by CUI.

2.2 Abbreviations

Abbrevation	Explanation
API	American Petroleum Institute
CoF	Consequence of Failure
CRA	Corrosion Resistant Alloy
CUI	Corrosion Under Insulation
EFC	European Federation of Corrosion
HDG	Hot Dipped Galvanized
IOGP	International Association of Oil and Gas Producers
NCS	Norwegian Continental Shelf
PoD	Probability of Detection
PoF	Probability of Failure
PSA	Petroleum Safety Authority, Norway
Ptil	Petroleumstilsynet, see PSA
TSA	Thermal Sprayed Aluminimum

3 BASIS FOR WORK

The basis for the work has been reference documents as listed in section 7, results from the workshop held with operators on the Norwegian Continental Shelf (NCS) on November 9th, 2021, see Appendix A, and DNV experience and knowledge related to CUI.

4 REGULATIONS, GUIDELINES AND STRATEGIES

4.1 Regulation and legislation

Norwegian legislative requirements for design and operation of offshore facilities are covered by the legislation from Petroleum Safety Authority. Requirements related to design with relevance for CUI can be found in the facilities regulations and requirements for insulation needs is covered both in paragraph §11, §12 and §29.

The Norwegian legislation, ref. the activities regulations chapter IX, including §47 – Maintenance programme, set requirements to the maintenance program for "failure modes that may constitute a health, safety or environmental risk". The guideline to §47 details that "*The DNV-RP-G101 guideline may be used to establish the inspection programme for process plants and auxiliary systems*".

The DNVGL-RP-G101 *Risk-based inspection of offshore topsides static mechanical equipment* was updated in January 2021 and the current revision refers to DNVGL-RP-G109 *Risk-based management of corrosion under insulation* for assessment of risk related to CUI, while the 2017 revision of DNV-RP-G101 gives a rate calculation formula for CUI.

The Management regulations § 23 Continuous Improvement and the Framework regulations § 24 Use of recognised standards is also relevant to management of CUI

4.2 Publicly available guidelines and standards

Based on a thorough review of available guidelines in the industry the following documents have been identified as the most relevant and are further detailed and compared in this report:

- API 581, "Risk-Based Inspection Methodology"/1/
- API 583, "Corrosion Under Insulation and Fireproofing"/2/
- DNVGL-RP-G109, "Risk Based Management of Corrosion Under Insulation"/3/
- Energy Institute, "Guidance for corrosion management in oil and gas production and processing"/6/
- EFC no. 55, "Corrosion-Under-Insulation (CUI) Guidelines"/5/
- HOIS-G-023, "Guideline for in-situ inspection of corrosion under insulation"/7/
- NACE SP0198, "Control of Corrosion Under Thermal Insulation and Fireproofing Materials – A systematic Approach"/4/

The 5 first documents are considered guidelines for management of corrosion under insulation, while the NACE document focuses on design to avoid CUI. The HOIS document focuses on NDT to detect CUI damage.

Highly relevant design documents such as NORSOK M-004 "Piping and equipment insulation" and NORSOK M-501 "Surface preparation and protective coating" were not included in this review as they are considered specific design documents for insulation and coating. These documents will also be the main input content of the new specifications issued by IOGP under the JIP33 initiative:

S-715 Coating and Painting for Offshore Coastal and Subsea Environment

S-738 Insulation for Piping and Equipment

4.2.1 Technical content of the reference documents

Table 4-1 describes the referred documents in 4.2 with respect to their technical content in the following categories:

- Risk
- Material degradation
- Coating
- Insulation
- Design
- NDT
- Maintenance
- Susceptible areas (Hot-spots / Focal points)

Table 4-1 Overview of technical content in selected documents relevant for managing CUI.

Standard	Risk	Material degradation	Coating	Insulation	Design	NDT	Maintenance	Susceptible areas (hot-spots)	Comment
API 581	Quantitative approach	Calculate corrosion rate. Basis is temperature and water wetting conditions	Use 3 different levels of coating protection (0, 5, 15 y)	Adjust Corr rate for insulation type (x 1,25 or x 0,75 or x 1)	Extensive minimum wall calculation incl stress calculations	Uses NDT results (Inspection efficiency) in calc of wall thickness	NA	NA	Quantitative risk analysis for refineries, Part 2 section 16 calculate damage factor for CUI in Carbon steel. Very detailed calculations using many simplifications.
API 583	Annex A (informative), qualitative approach	Describe the CUI degradation mechanism and identify factors affecting CUI	Listing different coating systems but refer to NACE SP0198 for details	Describe total 10 different types of insulation and some jacketing (cladding) types with advantages and disadvantages. Insulation techniques described in Annex B	Giving advice on how to design to avoid CUI, chapter 9.	Describe 12 different inspection methods with advantages and disadvantages	Giving advice on maintenance and repair strategies with respect to CUI	Chapter 5 (6 pages) identifying in total 57 focus areas distributed on general (20), vessels (10), piping (22) and tanks (5)	Describe different elements related to CUI. Advice on design (chapter 9), maintenance and mitigation (chapter 11)
DNVGL-RP-G109	Qualitative approach	Material degradation is assessed based on operating temperature	Lifetime of coating assessed based on 13 different coatings and quality of workmanship	Insulation and cladding assessed based on design solution and workmanship	Diameter and wall thickness is included in assessment	Referring to HOIS-G-G16 but set requirement to PoD	Effect of maintenance is included in risk update	Generic list of 11 focus areas	Focus on risk management
EFC no.55	Describe the RBI process for qualitative, semi-quantitative and qualitative analysis. Users are cautioned against commercial RBI programs that attempt to calculate corrosion rate for CUI	Describe the chemical degradation mechanism. Also present corrosion rate as a function of temperature (same as NACE SP 0198). Upper temp limit set to 175°C	Semi-Q assessment differentiating TSA and organic coating as well as QA/QC and “poor/high” quality coating. Also separate appendix D refer to NACE SP 0198 and Appendix E addressing TSA	Semi-Q assessment differentiating engineering standards, age and maintenance programs. Local environment is also addressed in the semi-Q approach. Insulation also covered in appendix F and G in EFC 55	Design for prevention of CUI is addressed in chapter 8, this cover design to avoid water wetting and use of CRA materials as well as TSA	Listing 13 different inspection methods with limitations, advantages and disadvantages. Table 6.2 gives effect of different local conditions on the ability of the NDT method. NDT methods also covered in appendix I of EFC 55I	As part of CUI mitigation (chapter 7), advise are given on best design / upgrade to avoid CUI. This includes TSA, CRA material and limited use of insulation. Appendix C1 cover “Maintenance and remediation issues”	Susceptible areas listed for different types of equipment (piping, vessels, heat exchangers) in chapter 5.3	Address elements such as cost, quality assurance, organization, responsibility, inspection strategies and CUI mitigation.

Standard	Risk	Material degradation	Coating	Insulation	Design	NDT	Maintenance	Susceptible areas (hot-spots)	Comment
Energy Institute «Guidance for corrosion management in oil and gas production and processing”	Referring to UK regulations for risk management. (Annex B3). Describing general work process for corrosion risk assessment (Annex F) referring to API 580/581 and DNVGL-RP-G101	Relate degradation of CS to age, temperature and water wetting without giving any formula or approach for assessing the PoF.	General comments and practical advice. Promote TSA if applied correctly opposed to organic coatings.	General comments and practical advice. Claim upgrade and control of insulation solution to be more relevant in late life than coating condition. Advice NOT to give too much weight to insulation type in CUI PoF assessment	Limited input	Refer to HOIS-G-023 for NDT methods Refer to DNV-RP-G101 for inspection effectiveness	Give some advice related to fabric maintenance and insulation maintenance	The term “prone areas” are used and described at a high level in I.12.5.3	To a large degree adjusted to fit UK regulation. All activities related to plan-do-check-act principles in the improvement loop. Annex I.12 address CUI. Referring to EFC no. 55 Recommend a set scheme (ref I.12.5.2) for a CUI RBI scheme given for High risk: regular CVI with removal of insulation in prone areas (every 2-4 year) combined with full strip and full CVI in less frequent intervals (every 7-10 year). For Medium risk less frequent inspection scope is recommended
HOIS-G-023	NA	NA	NA	Discuss different insulation solutions vs NDT	NA	Very extensive	NA	NA	Main focus is assessment of different NDT methods ability to find CUI. Describing application and limitations for both standard and advanced NDT methods
NACE SP0198	NA	Describe the degradation mechanism and influencing factors. Present CUI corrosion rate as a function of temperature (graphical)	Giving advice on different types of coating to be used under different conditions (temp.)	Describing application and limitation of 8 different groups of insulation material	Design to avoid CUI is addressed in section 3	Listing 9 methods without any details on application and limitations	NA	Listing total of 13 focus locations and 23 awareness elements.	Primarily giving advice for design.

4.3 Company specific strategies

A workshop with participants from 7 operators on the Norwegian Continental Shelf and onshore assets under PSA regulation was held November 9th, 2021. The main topic for this workshop was to discuss the respective operators' strategies to manage CUI, discuss experiences and learn from each other.

All operators had a specific strategy to manage CUI, two of these were based on internally developed methodologies, while 5 were based on acknowledged recommended practices: DNVGL-RP-G109 (3) and DNVGL-RP-G101, rev. 2017 (2). The latest revision of DNVGL-RP-G101, rev. 2021, refers to DNVGL-RP-G109 for assessment of CUI.

The differences in strategies also reflect the different type of assets the operator is responsible for. Where one operator might only have one relatively modern asset with extensive use of CRA materials, other operators have a wide variety of both old and new assets.

The involved companies have different work processes, although all could relate to plan-do-check-act principles, or the maintenance loop as described back in the 1990's. Obvious differences relate to how well the relevant disciplines are involved in the CUI management. One operator properly involved relevant disciplines in weekly meetings to discuss and manage CUI, while others had problems with alignment and cooperation between maintenance and technical integrity for example.

In the evaluation of probability of CUI, there exists large differences in complexity and number of parameters used in the assessments. The companies using the DNVGL-RP-G109 generally take more parameters into account than those using DNVGL-RP-G101. For the two internally developed methodologies there are large differences in complexity and use of parameters, where one methodology is close to DNVGL-RP-G109 in terms of number of parameters and approach, while the other methodology is rather simplistic, with few parameters used.

Several of the companies had specific CUI strategies for deck penetration and HDG bolts in CRA systems as this these were identified as specific design details that were exposed to CUI. Other noted challenges were low quality in the workmanship of insulation and coating for nozzles that led to increased CUI challenges after 10-15 years in operation.

The different operator-specific strategies could be divided into 4 main approaches:

- Use of DNVGL-RP-G109
- Use of DNVGL-RP-G101 rev 2017
- Use of internally developed strategy based on rate model, complex
- Use of internally developed strategy based on rate model, simplistic

Most companies base their CUI inspection campaigns on risk identification and visual external inspection followed by partial removal of insulation for close visual inspection of the coated steel.

4.3.1 Use of DNVGL Recommended Practices

The main difference between DNVGL-RP-G101, rev. 2017, and DNVGL-RP-G109 is that the former(G101) is based on a quantitative approach using a rate model as a function of temperature, while the latter (G109) is a semi-quantitative/qualitative model based on assessments of many more parameters, giving a probability of failure ranging from very low to very high. The latest revision of DNVGL-RP-G101, rev. 2021, refers to DNVGL-RP-G109 for assessment of CUI.

The DNVGL-RP-G109 approach is a semi-qualitative approach where several parameters are included in the assessment. The three companies using this approach use 13 to 17 parameters to assess the probability of CUI. This approach will enable a dynamic risk assessment where the update of risk based on relevant mitigation is important. The risk assessment will identify when the risk become unacceptable based on consequence of failure, condition of coating, condition of insulation (water wetting), design, material selection and operational temperature.

4.3.2 Internal company developed strategies

The complex internally developed assessment methodology holds several of the elements described in DNVGL-RP-G101 e.g., coating assessment. Time for mitigation is based on remaining life calculation given a calculated corrosion rate. The main features of the probability assessment relate to:

- Design of pipes and vessels (e.g. material type, pipe diameter, wall thickness)
- Coating type and insulation type
- Operating temperature
- Design pressure
- External conditions
- Consequence category

The resulting probability assessment will normally be on the conservative side based on assumptions such as consistently wet insulation, a corrosion model that assumes uniform corrosion opposed to the normally localised corrosion, and remaining life based on design pressure. The model does not take into account temperature fluctuations that might work the opposite way and remove some conservatism from the calculations. Note that temperature fluctuations are not included in any of the described methodologies in this report.

The simplistic internally developed assessment models are primarily based on CUI corrosion rate model in DNVGL-RP-G101 for coated and uncoated surfaces combined with a consequence category. Based on this rate model, a predefined inspection strategy is implemented. This methodology doesn’t normally take into account coating type and coating condition, insulation systems, water wetting, design details or relevant workmanship.

4.4 Design requirements leading to increased CUI risk

The use of insulation in oil and gas facilities are very extensive. Calculations for the need of passive fire protection (PFP) are often based on very conservative assumptions including fire load from a jet fire.

The requirements with respect to passive fire protection, ref §29 in the facilities regulations, often lead to increased risk of breach of the primary barrier (containment) to fulfil the requirements for the secondary barrier (escalation and evacuation). Also, the effect of deluge is not included in such calculations. The different operators have different ways of calculating the need for PFP.

There might be an unreleased potential in reducing the overall risk by better balancing the CUI risk with the PFP requirements and thereby reducing the need for insulation. A cross-discipline assessment of the actual need for insulation is recommended.

Regulations also sets requirements to testing fire water systems, which often leads to extensive water wetting of the process plant with sea water, and thereby creating a more corrosive environment than during normal operation without testing the deluge system.

4.5 CUI historical data

In general, there are limited data collected *and* made available to extract historical information regarding CUI rates or failure distribution. A study presented at EuroCorr in 2019 /8/ published the first marine upstream onshore plant CUI dataset for carbon steel piping and compared it with other existing datasets and API 581 prediction.

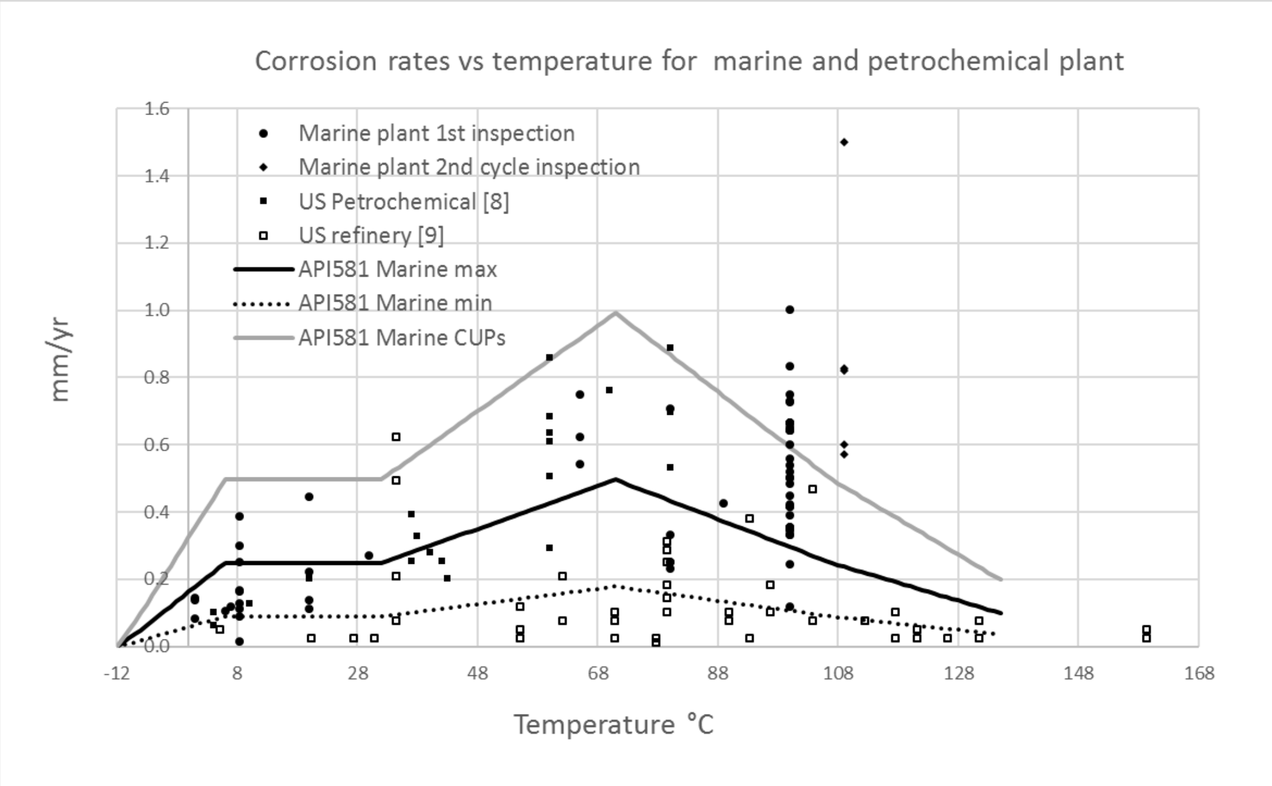


Figure 2 Comparison of CUI corrosion rate versus temperature from three plant carbon steel datasets.**/8/**

The paper emphasised that:

- Estimated corrosion rates are not the best way to present plant data due to assumptions of coating life and water ingress – the best way to report CUI data is metal loss versus age with first cycle inspection after extended periods from a large sample population particularly relevant. Failures versus age graphs are also useful.
- API581 adjustment factor metadata was not supported by these plant datasets. In Figure 4-2 API 581 underpredicted marine plant CUI at ~100°C, the API 581 adjustment factors not matching the majority data points.

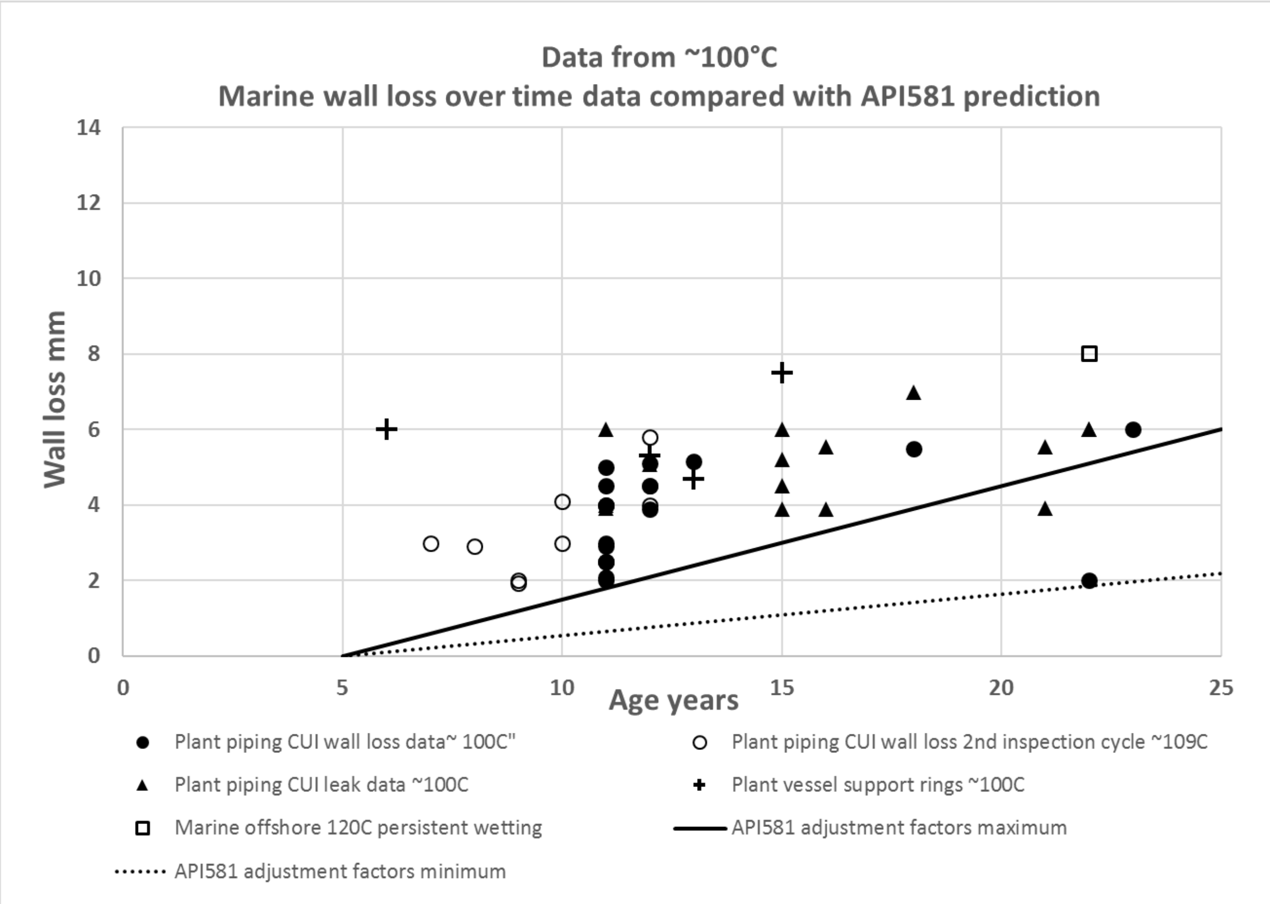


Figure 3 Comparison of marine wall loss versus age with API 581 prediction.**/8/**

The comparison study with API 581 and measured wall loss shows that API 581 underpredict the corrosion rate. This result is only based on limited data and will in such a context not be conclusive.

The same study /8/ also reviewed in total 10 guidelines and 8 in-house methods for CUI management and revealed several gaps and inconsistencies between the methods. In conclusion, it is stated that existing guidance is based on very limited actual plant data, with each dataset bringing valuable knowledge, but limited by lack of consistency of reporting and relevant metadata; more recent papers, though not all publishing raw data, reporting learning that optimizes timing of inspection and/or improved the hit rate of % inspection.

The in-house methods were reported as very simplistic.

Note that the study is not based on assets from the Norwegian Continental Shelf (NCS).

5 EVALUATION OF DIFFERENT STRATEGIES AND GUIDELINES

5.1 Guidelines

Based on the publicly available guidelines that have been reviewed, there are several similarities and none of the documents contradict the others. The main differences relate to the level of details and advice. Several documents are more descriptive (eg. API 583, NACE SP0198 and EFC no. 55) with respect to application and limitations rather than explicitly stating that one way is better than the other. This should be seen in context with a wide range of specific situations related to e.g. age, workmanship or local weather conditions to be considered and caution should be used to not rule out solutions for specific cases.

When describing CUI, challenges and possible solutions to CUI, the EFC no. 55 document is the most extensive and most relevant document. The document covers and exceeds all elements described in API 583 and NACE SP0198. The EFC. No 55 document is descriptive with respect to the risk management process but does not cover the topic in a sufficient way. The document describes a work process for risk assessment without describing a methodology as such. Risk mitigating effect and risk update is not included in the document.

For risk management of CUI, the DNVGL-RP-G109 will give a good recipe for both risk assessment, risk mitigation and risk update. The DNVGL-RP-G109 is based on a semi-qualitative approach to risk. For a quantitative method the API 581 should be considered.

NDT to detect CUI is described in several documents including the EFC no. 55. However, the only document that actually evaluates the different methods is the HOIS-G-023 document and it represents the most updated information related to NDT methods for CUI.

For a practical implementation of a CUI management system, it is also recommended to consider all the different practical advices that can be found in the Annex I12 in the Corrosion Management guideline from the Energy Institute.

5.2 Industry approach and strategies

The CUI challenge varies for the different operators depending on the design and age of the plant. For process plants designed with an extensive use of CRA materials, the CUI challenge will be reduced but awareness should still be raised for 316 material and carbon steel bolts in CRA systems.

For systems primarily designed in carbon steel, the CUI challenge might be seen after some years in operation, and for some systems with poor design or poor workmanship, CUI could be a challenge already in the first years of operation.

The industry approach, as seen through this study reflects the different designs, where the simplistic internally developed methodology is suitable for a company with one installation with extensive use of CRA materials, and the complex internally developed methodology using many parameters is suitable for an operator with multiple types of design with many years in operation.

For old systems primarily designed in carbon steel material, a more thorough approach should be used for CUI risk management or just be replaced by extensive inspection and refurbishment. This is not the case for all operators.

The use of DNVGL-RP-G101, rev. 2017, which describes a CUI corrosion rate based on temperature combined with a simplified model for coating degradation, might give too low corrosion rates, and thereby a too low probability of failure, followed by an underestimated risk.

5.3 Implementation

The implementation of a CUI management strategy will require continuous attention and updates of the present risk. Such updates need to reflect both the type of mitigation performed, as well as the extent of such mitigation. The continuous awareness will lead to a dynamic risk management approach based on present conditions, opposed to a static mitigation program based on fixed intervals.

Such a recommended dynamic approach to risk management is not implemented by all operators and relative static programs with predefined inspection content are used by several operators.

Successful implementation will also require an organisational setup to enable efficient communication and including involvement of all relevant disciplines. One operator facilitates the communication by arranging weekly meetings involving the relevant disciplines to address CUI specifically, while other operators struggle to have efficient communication with relevant disciplines. The use subcontractors in this setting might also reduce the effectiveness of a good CUI management implementation dependent on the possibility to achieve good communication lines with all involved stakeholders.

6 CONTINUOUS IMPROVEMENT AND LESSONS LEARNED

The operators from the oil and gas industry in Norway have a CUI forum that is arranged by DNV twice a year for common sharing of knowledge and experiences. This forum helps the industry at large to become smarter and make better decisions related to CUI.

6.1 Trends

The reported hydrocarbon leaks due to CUI ref Figure 1 has for the last 10 years (2011 – 2020) been on an average of 3 incidents on an annual basis without any specific positive or negative trend. Reported leaks before 2008 indicate an average of 1 incident annually. This increase over the last years might be caused by older assets more exposed to CUI but it can also be a result of increased awareness and better reporting routines with respect to root cause of the leak.

In the later years the material selection for static process systems on new builds has reflected more use of corrosion resistant alloys, which in general reduce the CUI potential. However, CRA systems often are still designed with the use of HDG carbon steel bolts and nuts, which will remain a CUI threat. The selection of coating systems has also been more focused on proper CUI protection and thermal spray aluminium (TSA) is also used more extensively. TSA has proven to provide significantly longer protection towards CUI provided it is applied correctly.

Over the last years new insulation systems based on aerogel have been qualified for piping systems. These products claim to be hydrophobic, i.e. water repellent and they also require less volume to ensure proper insulation. Up to recently, aerogel products have only been used by a few operators on NCS.

One operator in Norway has increased the CUI focus and has for many years performed extensive testing and qualification of coating and insulation systems. This testing has been beneficial to the entire industry as it has been in addition to the in-house testing performed by coating and insulation manufacturers.

The use of insulation spacers between pipe and insulation to improve water drainage has now become a well proven technique. It was introduced as early as 2007 in Norway and has shown good results in terms of reduced water wetting of the insulation.

Moisture monitoring in the insulation is being explored by several operating companies and several suppliers can deliver different solutions. Such service solutions will require ATEX certified, low-cost sensors with long battery lifetime and an efficient installation method. Furthermore, systems for data gathering and decision support need to be in place. This monitoring technology will most probably be implemented for critical systems for several operators in the years to come.

Within the field of NDT for detection of CUI there has been many recent developments but most of the new promising techniques will still only detect larger defects. In this context the work done by HOIS to quantify the ability to detect CUI is very valuable and enables the industry to make better decisions regarding use of NDT methods. The most promising method “Open Vision” is still not allowed in Norway due to radiation regulations.

The competitive situation and cost focus by operators with respect insulation and coating discipline has lead to low rates and poor recruitment to these trades, followed by increased use of foreign workers. The required trade certificates might not always be in place and personnel are often on short-term assignments. These elements can all have a negative impact on the workmanship and thereby the end quality of the final insulation and coating system.

6.2 Best Available Technology

For new builds, the best design for CUI will include the use of thermal spray aluminium (TSA) and insulation products that do not retain water or enable efficient water drainage.

For assets in operation, it will remain important to manage the embedded risk of CUI through good dynamic risk management, knowledge of the asset condition, and well-planned mitigation. This will include the use of:

- Well-implemented CUI risk management guideline
- Inspection and monitoring that confirm or adjust risk by increased knowledge and reduces uncertainty
- Mitigation plans that reduce the risk to an acceptable level

The current most relevant CUI guidelines are described in this document, all available for the industry. The introduction of a barrier approach introduced in DNVGL-RP-G109 is well received by operators in Norway.

Advanced NDT methods developed lately to identify CUI are still not efficient enough, with the potential exception of the “Open Vision” system. This system has shown good results but is not yet allowed in Norway due to radiation safety regulations. Inspection methods based on guided wave ultrasonic and pulsed eddy current show potential but will still need to achieve a better probability of detection for small, deep CUI flaws. There are ongoing processes to enable such technology for the Norwegian market.

Moist sensors are available for the industry and will give better information of the water wetting situation in the insulation and thereby help operators to better assess the risk of CUI.

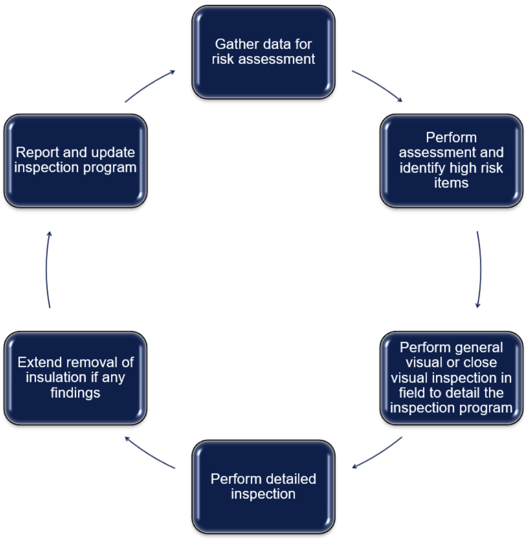
For the mitigation of CUI several new insulation and coating systems has been qualified and taken into use. Company strategies should include the use of new systems for better CUI management and not just use the same insulation and coating systems that has been used earlier.

6.3 Operator experiences

Operators consider CUI as the "*biggest threat to the mechanical integrity of oil and gas industry facilities*". Most operators consider CUI as a complex degradation where it is difficult to predict location of CUI attacks.

The general work process for the operators, independent of their CUI risk assessment model consist of the following steps:

1. Gather data for risk assessment
2. Perform assessment
3. Perform general visual or close visual inspection in field to detail the inspection program
4. Perform detailed inspection, often a combination of close visual inspection of external cladding and close visual inspection of piping and vessels after removal of insulation
5. Extend removal of insulation if any findings
6. Report and update inspection program



It is considered important to use local facility knowledge in combination with analysis to identify potential location for CUI. Experience from several operators indicate that the following object should be given high focus:

- Deck penetrations
- Carbon steel bolts in CRA systems
- Nozzles of pressure vessels
- Corrosion Under Pipe Supports (CUPS)

Some of the operators also have specific CUI programs to address these mentioned geometric features.

The implementation of DNVGL-RP-G109 is found to be easy and will give a good baseline for CUI-RBI. However, it is also identified challenges to adapt historical data when using DNVGL-RP-G109. For new inspections reporting parameters can be aligned with requirements for information in mentioned guideline. This will lead to a better data driven decision process in the way forward. It is reported that 50% of the operators actively use historical data in their CUI management. There is a large variation on which parameters the different operators use as input for CUI probability assessment, but all or most operator use material data, temperature, coating type and inspection results as input

Most operators express that they use field survey by Field Engineers and Inspectors to identify the locations most exposed to CUI and some operators are also having good experience with use of digital twin in planning phase.

Several of the operators are seeking to optimize the use of insulation. Optimize, in this context means to reassess the actual need for insulation and potentially remove or partly remove insulation to eliminate CUI risk. In general, the operators consider the insulation as wet until the opposite is confirmed. Thermographic inspections are also used to identify wet areas of the insulation.

Workmanship within insulation and cladding from project phase has strong impact on condition during late life operation

One operator experience that a weekly cross-discipline forum and close cooperation with insulation inspectors give a improved CUI management while others struggle to achieve a sufficient cross discipline internal cooperation.

Examples from inspection campaigns (radiographic and close visual inspection) for CUI indicate very high degree of flaws in inspection campaigns, above 25% with one sever finding of 50% wall reduction. In general, the identified flaws vary in size and few need to be mechanical repaired. Based on the feed-back from the operators the most common consequence of CUI is coating repair.

7 CONCLUSION

Corrosion under insulation is and will continue to be a major threat to the technical integrity of oil and gas assets. The embedded risk of a potential hydrocarbon leak is managed in different ways by the operators. The public available documents give guidance on the implementation of CUI management systems and some operators follow such guidelines while other operators have developed in-house methodologies. Some of the public available guidelines and some of the in-house developed documents might be simplistic and can underestimate the risk.

Operators differentiate significantly in the use of input data in the assessment of the CUI threat, and it is assumed that more extensive use of data will promote more correct risk evaluations.

In general, the oil and gas industry give high focus to the CUI threat and there are several initiatives amongst the operators that has led to successful implementation of better technical solutions.

Several improvements areas are identified and many of these can be solved through industry cooperation.

- Different approaches with respect to design of passive fire protection. A best practice could be identified and should be shared with the industry
- There is no existence of good historical data sets for CUI damage. A joint effort might result in better data-driven decisions and adjustments to current strategies
- Qualification of new technology could be organised with the involvement of multiple operators and sharing of results to the benefit of the industry
- Facilities regulations to be updated with reference to EFC 55
- Activities regulation to be updated with reference to DNVGL-RP-G109
- Existing reference in activities regulations to DNVGL-RP-G101 to be updated with reference to DNVGL-RP-G101 revision 2021.

Awareness should be raised for the following:

- A comparison study with API 581 and measured wall loss shows that API 581 underpredict the corrosion rate.
- The use of DNVGL-RP-G101, rev. 2017, which describes a CUI corrosion rate based on temperature combined with a simplified model for coating degradation, might give too low corrosion rates, and thereby a too low probability of failure, followed by an underestimated risk.
- Simplistic CUI assessment models with the use of few input parameters might underpredict the probability of failure
- Different approaches and methodologies might cause different gaps and key learning across companies might become less relevant

8 REFERENCES

/1/ API Recommended Practice 581, “Risk-Based Inspection Methodology”. Third edition April 2016, Addendum 1, 2019 and Addendum 2, 2020

/2/ API Recommended Practice 583 “Corrosion Under Insulation and Fireproofing” First addition May 2014.

/3/ DNVGL-RP-G109 “Risk Based Management of Corrosion Under Insulation” rev. December 2019.

/4/ NACE SP0198 “Control of Corrosion Under Thermal Insulation and Fireproofing Materials – A systematic Approach” rev. July 2017

/5/ European Federation of Corrosion (EFC) Publication number 55 “Corrosion-Under-Insulation (CUI) Guidelines” revised edition 2017

/6/ Energy Institute “Guidance for corrosion management in oil and gas production and processing” second edition March 2019

/7/ HOIS-G-023, HOIS/OGTC Guideline for in-situ inspection of corrosion under insulation (CUI), Issue 1, March 2020

/8/ Eurocorr2019-226986 “Using industry data to compare performance of different risk-based methods for management of corrosion under insulation” PhD C. Watt, PhD Chi-Ming Lee, S. Paterson, A. Jopen.

APPENDIX A
Work shop

A1. WORKSHOP AGENDA

The agenda for the workshop was:

- Introduction and welcome
- Background
- Presenting CUI questionnaire feed-back
- Technical topics and discussions
    - Main challenge
    - Work process
    - Probability assessments
    - Findings and management of findings
    - Reporting and learning
- Success and Challenges

A2. PARTICIPANTS

The following companies were represented during the workshop:

- AkerBP
- Alterra Infrastructure
- ConocoPhillips
- Equinor
- Gassco
- Lundin
- Norske Shell
- Vår Energi

Organizers:

- Petroleum Safety Authority
- DNV

A3. BACKGROUND

The objective and background for the workshop were presented by Petroleum Safety Authority.

Main objective was to identify how operators and rig owners on the Norwegian Continental Shelf (NCC) is working to manage the CUI threat with regard to pressure containing equipment and how effective the different practices are related to:

- Understand the application and limitations of the various approaches, including the use of standards

- Understand how and to what extent the methodology is implemented and how the relation is between theoretical approach and practical execution
- Discuss potential improvement areas and how to learn from each other's experiences

A4. REGULATORY REQUIREMENTS

The following regulations are considered as most relevant related to CUI management:

- The Facilities regulations § 12 Materials
- The Activities regulations § 45 Maintenance
- The Management regulations § 23 Continuous Improvement
- The Framework regulations § 24 Use of recognised standards

A5. FEEDBACK QUESTIONAIRE

Prior to the workshop all invited operators and rig owners were asked to give feedback on the following:

- What is your companies main challenge(s) with respect to avoiding a major accident due to corrosion under insulation? See A5.1
- How do you detect CUI? See A5.2
- What is the most common immediate consequence of CUI? See A5.3
- How is your assessment model for CUI built? See A5.4
- Parameters used in CUI probability assessment. See A5.5

Feedback was received from 7 operator. In the following presentation of the results, all answers are anonymised and are presented as “number of answers” per given category.

Note that difference in scale, age and design of the various operated assets may influence the answers given.

A5.1. Question: Main challenges

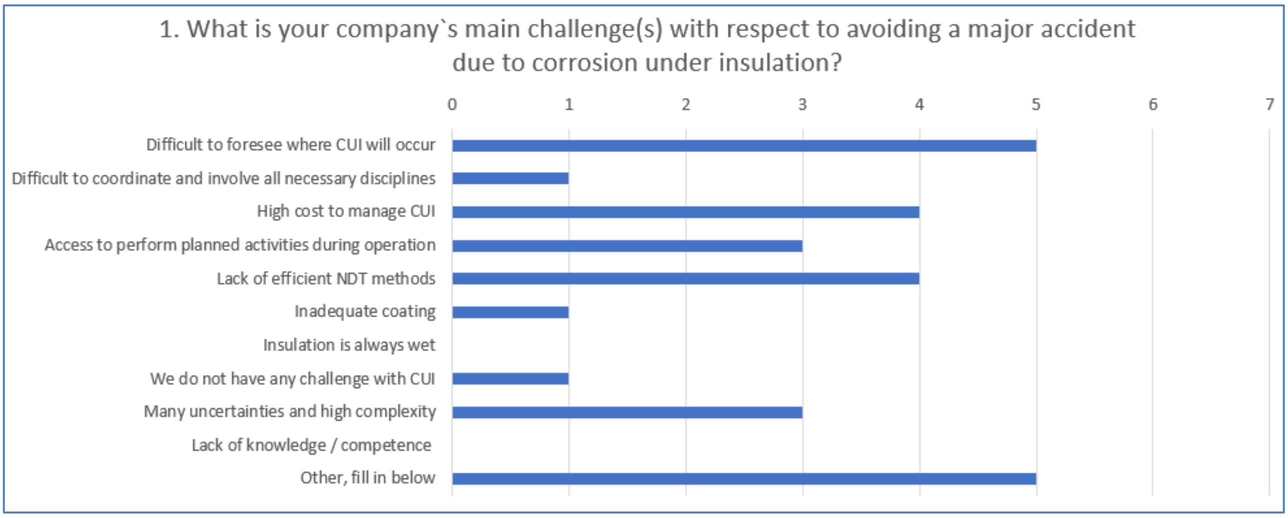


Figure 4 Summary of results Question 1

Figure 4 Summarises the answers to question 1. The following main take-away may be drawn from the answers and discussions during the workshop:

- All operators states that there is enough relevant competence available
- Most operators find it difficult to predict where CUI will occur
- More than 50% of the operators indicates that there is a lack of suitable NDT methods available
- More than 50% of the operators points out that there are major costs connected to CUI management

General comments

Some of the predefined statements were somewhat difficult to interpret and answers may be influenced of each companies' interpretation.

Most operators gave separate comments which all can be summarised as highlighting the complexity of the CUI threat, the challenges related to scope size, resource requirements and the varying quality of workmanship related to coating and insulation.

A5.2. Question: Detection of CUI

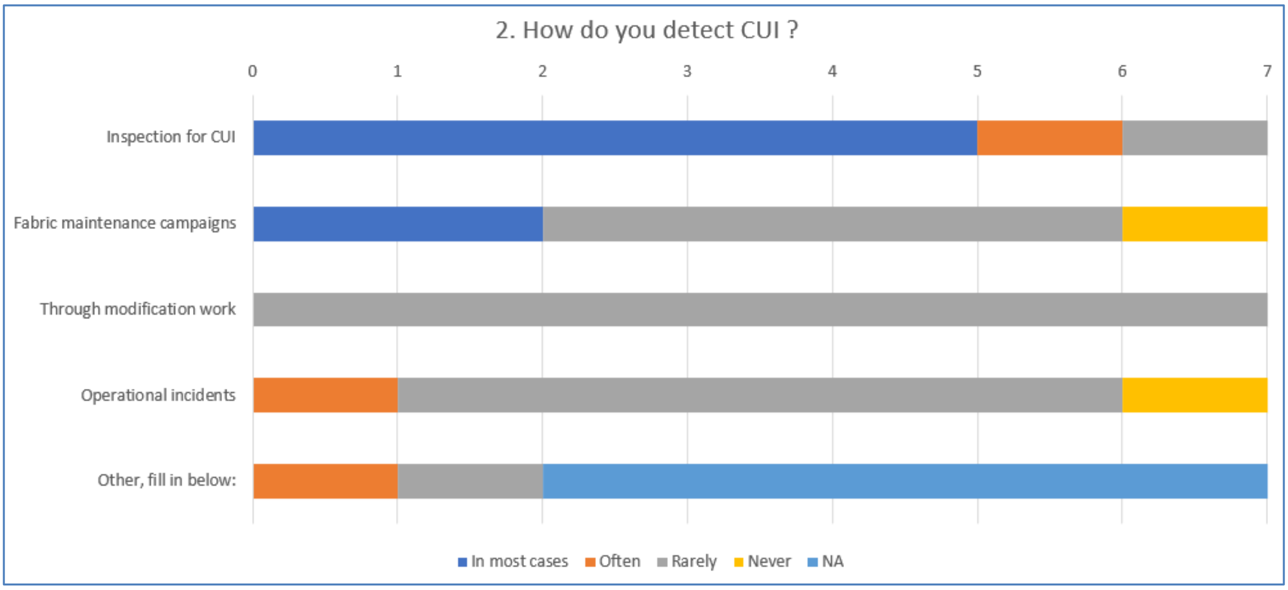


Figure 5 Summary of results Question 2

Figure 5 summarises the answers to question 2. The following main take-away may be drawn from the answers and discussions during the workshop:

- Most operators have developed a dedicated strategy for CUI inspection activities
- Most CUI indications are reported through inspection or fabric maintenance activities
- Some answers indicates that certain operators have assets with a robust design, e.g. large extent of corrosion resistant alloys and adequate surface protection, minimizing CUI as a threat

A5.3. Question: Most common immediate consequences

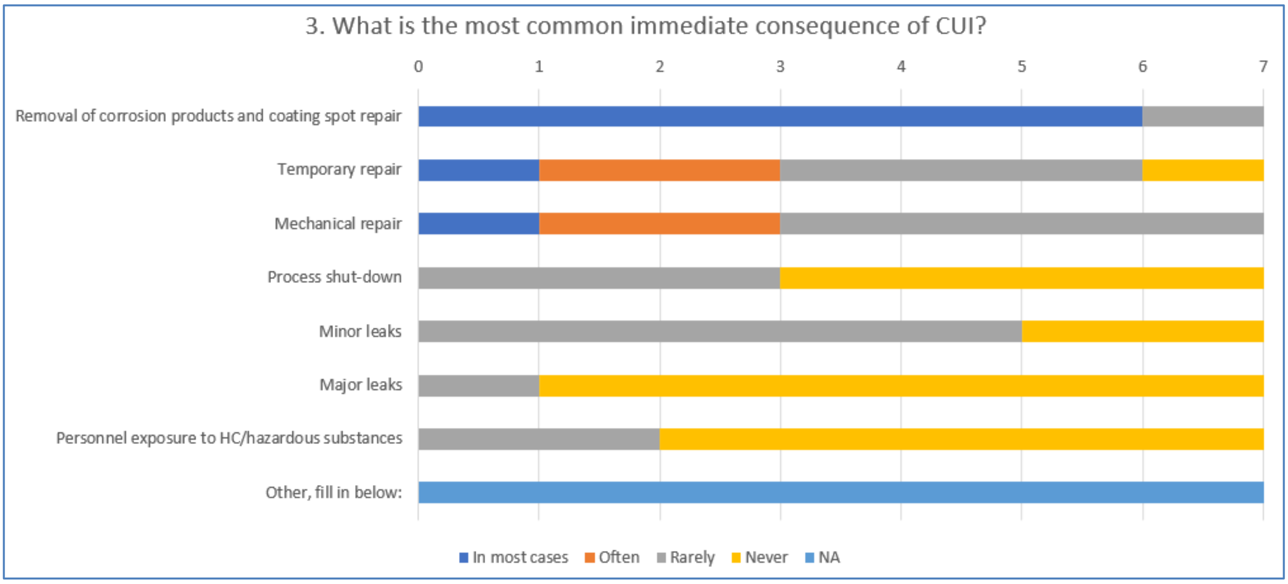


Figure 6 Summary of results Question 3

Figure 6 summarises the answers to question 3. The following main take-away may be drawn from the answers and discussions during the workshop:

- The most common consequence of CUI is repair of surface protection or insulation system through fabric maintenance
- Temporary repairs are also used, mostly in form of clamping or composite repairs. Some operators are restricted by company specific procedures to limit use of temporary repairs.
- Mechanical repairs are mainly often or rarely a consequence of CUI
- Leakages, unintentional shut-down and personnel exposure to HC/hazardous substances are rarely an immediate consequence of CUI

General comments

Some of the predefined statements were somewhat difficult to interpret and answers may be influenced of each companies' interpretation.

CUI incidents reported to the Petroleum Safety Authority is limited to leakages with leak rates larger than 0,1 kg/s.

A5.4. Question: Assessment model

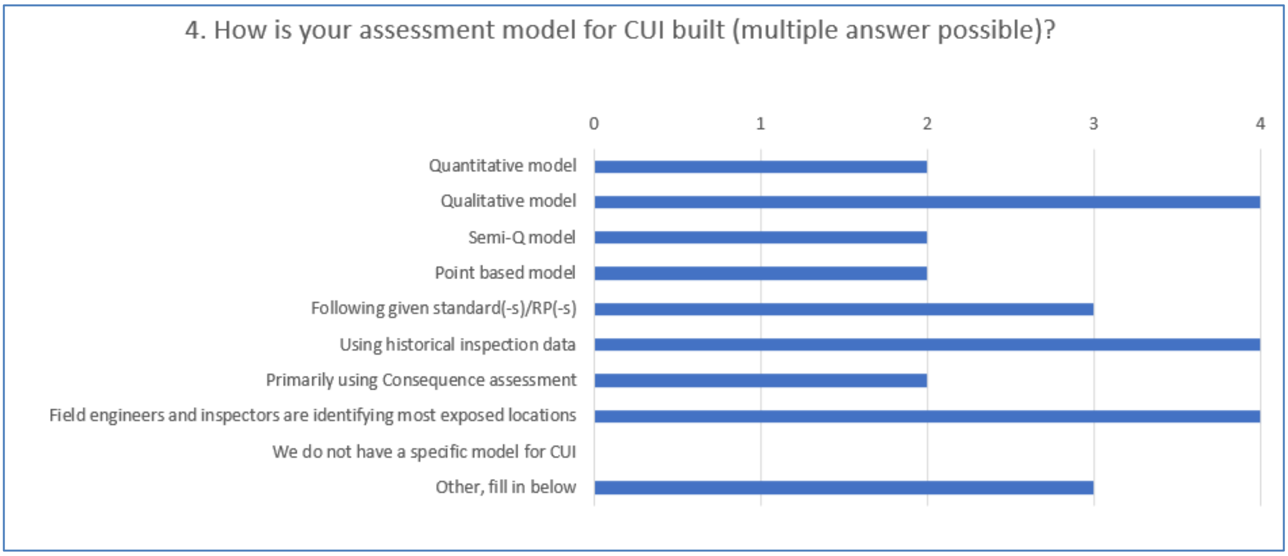


Figure 7 Summary of results Question 4

Figure 7 summarises the answers to question 4. The following main take-away may be drawn from the answers and discussions during the workshop:

- All operators have a specific model for CUI, but only three operators indicate the model used follows a standard or RP. DNV-RP-G109 is the only standard/RP used
- Most operators express that they use field survey by Field Engineers and Inspectors to identify the locations most exposed to CUI.
- About 50% of the operators replies that they use historical data in updating their CUI model / RBI.
- Comments provided in the questionnaire indicates, that for some operators, CUI assessment is included in the general RBI assessment

General comments
Some of the predefined statements were somewhat difficult to interpret and answers may be influenced of each companies' interpretation, mainly related to the interpretation of "Point based model" and the difference between "Quantitative", "Semi-Quantitative" and "Qualitative" models.

A5.5. Question: Parameters for probability assessment

5. Parameters used in CUI probability assessment	6	6	17	16	13	7	13
	Company A	Company B	Company C	Company D	Company E	Company F	Company G
Type of material	Y	Y	Y	Y	Y	Y	Y
Operational temperature	Y	Y	Y	Y	Y	Y	Y
Temperature fluctuation	N	N	N	N	Y	N	N
Type of coating	N	Y	Y	Y	Y	Y	Y
Age of coating	N	Y	Y	Y	Y	N	Y
Quality of coating	Y	N	Y	Y	N	N	Y
Local environment, access to water	N	N	Y	Y	Y	N	Y
Dew-point	N	N	Y	N	N	N	N
Insulation type	N	Y	Y	Y	Y	N	Y
Cladding type	N	N	Y	Y	Y	Y	Y
Cladding workmanship	N	N	Y	Y	N	Y	Y
Wall thickness	Y	N	Y	Y	Y	N	Y
Pipe dimensions	N	N	Y	Y	Y	N	Y
Lay-out	N	N	Y	Y	Y	N	N
Inspection results	Y	Y	Y	Y	N	Y	Y
Inspection extent	N	N	Y	Y	N	N	N
Heat tracing	N	N	Y	N	Y	Y	N
Material selection in nuts and bolts	Y	N	Y	Y	N	N	Y
Other elements	N	N	N	Y	Y	N	N

Figure 8 Overview of results Question 5

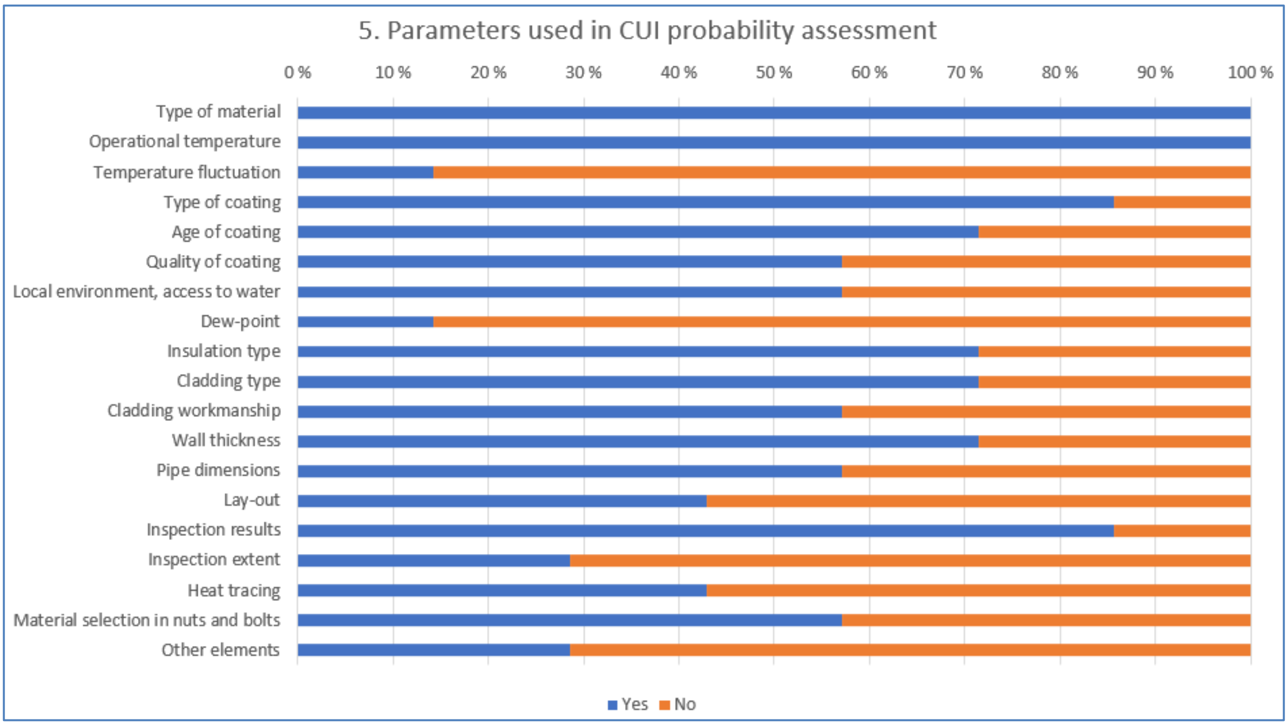


Figure 9 Distribution of answers Question 5

Figure 8 and Figure 9 summarises the answers to question 5. The following main take-away may be drawn from the answers and discussions during the workshop:

- There is a large variation on which parameters the different operators use as input for CUI probability assessment, but all or most operator use material data, temperature, coating type and inspection results as input
- Figure indicates that 4 operators have a high number of input parameters included in their probability assessment, and 3 of them are utilising DNVGL-RP-G109 as basis for their assessment model while 1 has an inhouse developed model
- The discussions during the workshop pointed out the difference in CUI data availability based on insulation age and design, which limits the possibility to utilize several of the mentioned input data sources

About DNV

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