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Corrosion- Under-Insulation (CUI) Guidelines

Revised Edition

Edited by S. Winnik



Corrosion-Under-Insulation (CUI) Guidelines: Revised Edition

Series introduction

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S. Winnik



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Introduction

The original document was dedicated to Terry Hallett who worked for Shell (UK) and died unexpectedly in 2005. He was one of the key early contributors to the development of this document. His enthusiasm inspired his friends and colleagues, from within Shell and from other companies, to ensure that the work he initiated would be completed. CUI is not one of the work areas that typically inspire us, but, despite an exceptionally heavy workload Terry spared no effort to further the interests and activities of both the UK CUI Forum and the EFC and played a key role in both associations. All who came into contact with him will remember Terry for his sincerity and his sense of humor. He has been sorely missed.

As the editor, I know that the document would not have been completed without the many contributions from the primary authors of this document. We all know that writing a document by committee is never easy. Special thanks are extended to Hennie DeBruyn (Borealis, now at Aramco), Andrew Kettle (ChevronTexaco, now at ExxonMobil), Rob Scanlan (ConocoPhillips, now at BP), Staffan Olsen (Scanraf), Carmelo Aiello (ENI now retired), Nicholas Dowling (Shell), Maartin Lorenz (Shell—recently passed away), Francois Ropital (IFP), and John Thirkettle (UK CUI Forum) for their efforts throughout the development of this document.

The original document, first published in 2008, was very successful and provided an important resource in the continuing battle to mitigate CUI. Many members of the EFC corrosion community requested an update and this process has taken between 18 and 24 months. Unfortunately, not many meaningful developments have come to market since the original publication so this document is just a revision. Hopefully, this revised document will continue to serve the community until the next revision, whenever that may be.

The document would not have been completed without the many contributions from the members of EFC WP15. Significant contributions were made by Hennie DeBruyn (Aramco), Johan Van Roij (Shell), John Sentjens (Temati), Fred Van Rodijnene (Sulzer Metco), John Pugh (BP), and Adam Ovington (International Paints).

Dr. Stefan Winnik
Editor

SW Materials and Corrosion Ltd. (Formerly ExxonMobil)

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Introduction

1

The term “corrosion under insulation” (CUI) refers to the external corrosion of piping and vessels fabricated from carbon manganese, low alloy, and austenitic stainless steel that occurs underneath externally clad or jacketed thermal or acoustic insulation primarily due to the penetration of water. By its very nature CUI tends to remain undetected until the insulation and cladding/jacketing is removed to allow inspection or when leaks to atmosphere occur. CUI is a major problem worldwide and is shared by all of the Oil&Gas (both onshore and offshore), Chemical processing industries (CPI), and related industries. It is not a new problem, but it can be a serious problem. CUI has been responsible for many major leaks that have led to safety, health, and environmental (SHE) related incidents, to lost production, and is responsible for the large maintenance budgets that are often required to mitigate the problem.

Corrosion of austenitic stainless steels is localized and usually a combination of pitting and chloride external stress corrosion cracking (Cl-ESCC). Although Cl-ESCC¹ of insulated austenitic stainless steel was first reported in 1965, very limited published information was available on the CUI of carbon manganese and low alloys steels and Cl-ESCC of austenitic stainless steels up to 1980 when a meeting was held in the November of that year.² Richardson³ provided a review of this very successful, 2-day meeting during a combined ASTM/NACE/MTI sponsored symposium held in 1983.⁴ When reviewing the literature from that meeting today, it would appear that the problems reported in 1980 mirror the experiences currently being reported.

Although numerous instances of CUI are reported annually, this has not been reflected in the current industry standards for insulation or other measures used to mitigate CUI. The first ASTM standard on thermal insulation materials relevant to CUI was only adopted in 1971.⁵ The NACE Task Group T-6H-31 first issued a report on CUI⁶ in 1989 and later NACE Task Group T-5A-30 became an open forum for industry CUI problems and solutions. This led to the publication of a NACE recommended practice RP0198⁷ in 1998. RP0198 was revised in 2004⁸ and republished in 2010 as a standard practice SP0198 in 2010.⁹ Other conferences and initiatives covering CUI and insulation materials have taken place since 1983 but the problem remains unresolved. It would seem that the incidence of CUI examples is not diminishing and would appear to be increasing given the number of instances being reported. A NACE conference in 2003 reviewed similar topics first discussed in 1983, which was well illustrated by Delahunt¹⁰ who presented an excellent historical perspective of the occurrence of CUI. A conference held in the UK in 2004¹¹ had a similar theme and again suggested that CUI had not been mitigated and that instances of CUI were actually increasing. These instances led to the formation of an informal group based in the UK (UK CUI Forum)¹² by corrosion and materials engineers from a number of major oil and gas producers in the UK specifically to share CUI related information. The Forum has since expanded and now includes representatives from other industries. Collaboration between the UK CUI Forum and the European Federation of Corrosion

(EFC) led to the development of this document, EFC Number 55 “Corrosion Under Insulation Guidelines (CUI)”¹³ first published in 2008.

Why does CUI occur? CUI of carbon manganese and low alloy steel usually occurs when a number of conditions are fulfilled:

- Water or moisture must be present on the substrate in order to allow oxygen corrosion to occur. Water ingress is due to breaks in the insulation cladding/jacketing which may have resulted as a consequence of poor installation, damage during service, or simply as a result of deterioration over time. The principle sources of water are:
 - External sources, which include rainwater, deluge systems, and process liquid spillage, and
 - Condensation

This water may be retained depending on the absorption properties of the insulation material and the operating temperature. Depending upon process conditions, saturated insulation may never have the opportunity to dry out completely.

Generally CUI is classified into one of four categories:

- Low temperature (cold or cryogenic)
- Sweating service (below dew point)
- High temperature
- Cyclic temperature

All of the four CUI categories are influenced by location or geography and prevailing local climatic conditions. This is especially pertinent for equipment operating below ambient temperature or in sweating service with the CUI rate being influenced by the average ambient temperature and humidity. The temperature and humidity controls the dew point and it is the dew point that controls the degree of wetness. Figure 1.1 shows the dew point annual variation in three different regions

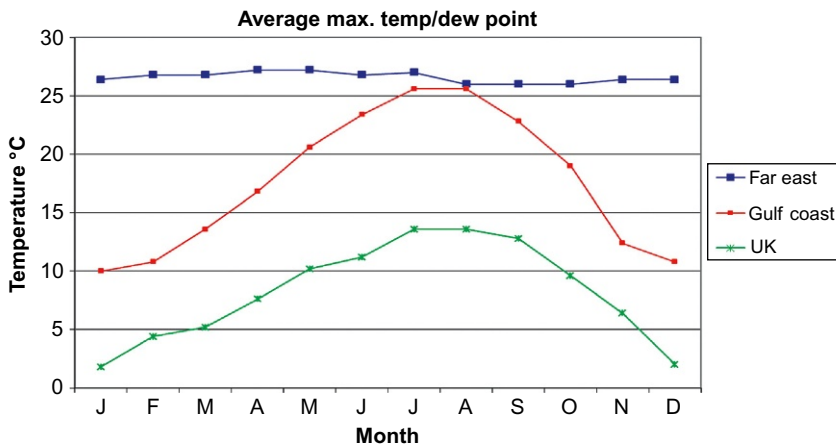


Figure 1.1 Influence of annual variation in temperature and dew point in different regions on the degree of wetness.

and clearly illustrates the influence of dew point on the degree of wetness and possible CUI for equipment operating at the same temperature.

Contaminants that can cause problems on both carbon manganese and low alloy steel as well as austenitic stainless steel need to be present. Chlorides and sulfides make up the bulk of the contamination and generally increase the corrosivity of the water. The source of the contaminants can be external, such as environmental borne chloride sources at sites situated in a marine environment (e.g., offshore) or wind borne salts from cooling tower drift, or from periodic testing of firewater deluge systems. Contaminants can also be produced by leaching from the insulation material itself. In the presence of an applied or residual stress and temperatures exceeding 60 °C (140 °F), high chloride contents of water contribute to chloride external stress corrosion cracking (CI-ESCC).

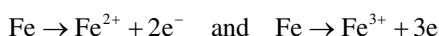
The operating temperature range of the piping or vessels should be between -4 and 175 °C (25 and 347 °F). This temperature range reflects the experience of the contributors to this document and is meant as a guide to enable mitigation procedures to be developed. CUI problems have been reported outside this range; the majority CUI occurrences are, however, within the -4 and 175 °C (25 and 347 °F) specified. In general, the metal temperature will be approximately the same as the process operating temperature (for insulated equipment). However, if the insulation is damaged and/or highly humid conditions commonly exist, a process temperature significantly above 121 °C (250 °F) can result in metal temperatures low enough to cause CUI, therefore the CUI range is extended to 175 °C (347 °F). In addition, equipment subject to cyclic temperatures even outside of this range (e.g., regeneration equipment) or dead legs (including “cold” dead legs nominally operating below -4 °C and warming up to ambient temperatures) should be considered to be subject to CUI. Systems that utilize heat tracing require careful consideration.

The insulation type may only be a contributing factor because CUI has been reported under all types of insulation. However, the individual insulation characteristics can influence the rate at which CUI occurs. These include:

- Presence of water-leachable contaminants such as chlorides and sulfates;
- Water retention, permeability, and wet-ability of the insulation;
- Any residual compounds that may react with water to form hydrochloric or other acids;
- An annular space or crevice for the retention of water and other corrosive media;
- Possible absorption of water; and
- Possible contribution of contaminants that increase or accelerate the corrosion rate.

CUI is electrochemical and requires the presence of four elements; an anode, cathode, electrolyte, and an electrical circuit or path. The electrolyte in its simplest form is oxygenated water, which may contain contaminants that can increase the corrosion rate. [Figure 1.2](#) provides a simple overview of the electrochemical reaction.

Oxidation reaction



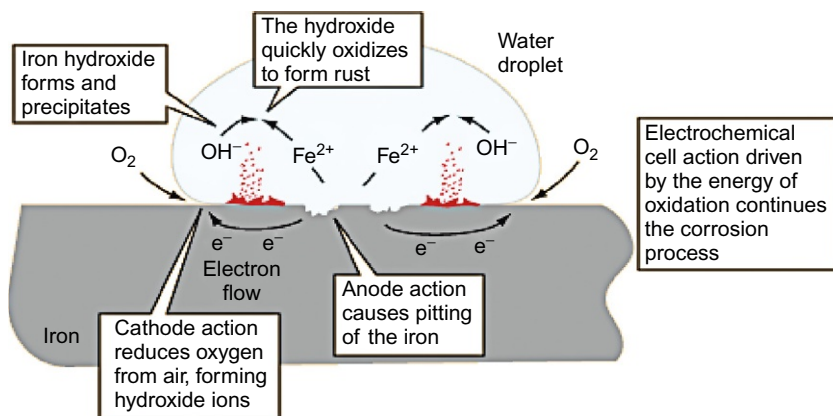
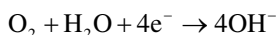
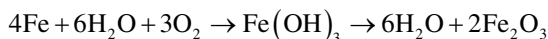


Figure 1.2 CUI of carbon steel is essentially an electrochemical reaction.

Reduction reaction



The OH^- reacts with the Fe^{2+} and Fe^{3+} to form $Fe(OH)_2/Fe(OH)_3$ and Fe_2O_3 is precipitated.



Cl^- contaminants promote oxidation of Fe^{2+} to Fe^{3+} , which lowers the pH and accelerates corrosion (via reduction of H^+ ions). SO_2 acidifies the water and also promotes the reduction of H^+ ions.

The above assumes absence or breakdown of any protective coating that may have been applied.

Figure 1.3 shows how the electrochemical reaction occurs in real applications beneath “hot thermal” insulation. Water or moisture penetrates the insulation and will either be absorbed or trapped by the insulation. Eventually the water will make contact with the hot metal surface. Evaporation will occur, which drives the water vapor through the insulation towards the “cold” external barrier where condensation occurs. Water will then migrate again, back toward the hot metal surface. A number of other processes also occur during this process. Contaminants can be concentrated due to the cyclic or reflux nature of the evaporation/condensation cycle and degradation of a coating, if present, can occur. Eventually, the coating will be damaged sufficiently to allow electrochemical corrosion to initiate. The evaporation/condensation cycle can also damage the insulation, reducing the effectiveness/thermal properties. This process occurs in all insulated systems—both open cell and closed cell insulation is prone to CUI.

It follows that the insulation system that holds the least amount of water and dries most quickly should result in the least amount of corrosion damage to equipment. The absence or the presence of a damaged barrier coating will allow direct contact between the water and the piping or vessel surface which will allow corrosion to occur.

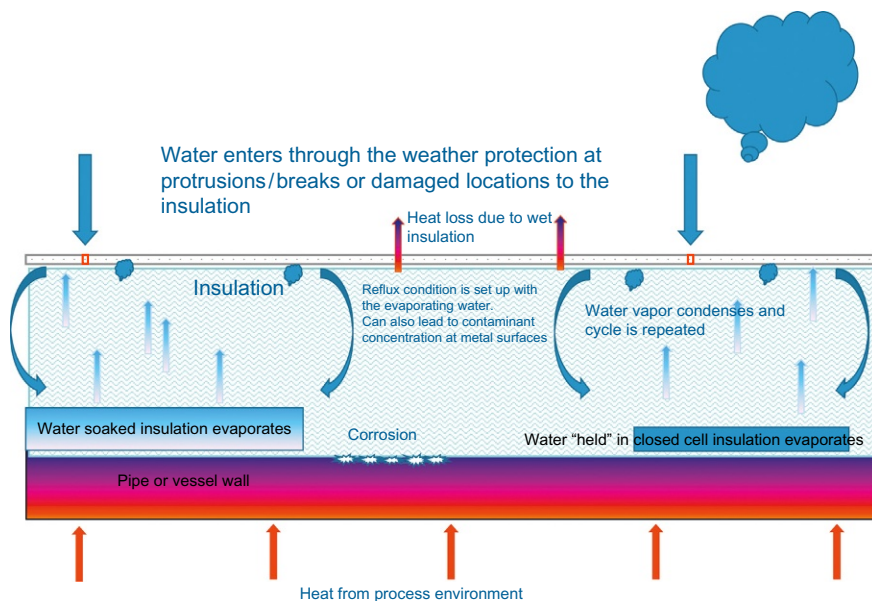


Figure 1.3 CUI (hot) in action.

The rate of CUI is determined by the availability of oxygen, contaminants in water, temperature and the heat transfer properties of the metal surface, and wet/dry conditions of the surface. This, in turn, is influenced by the properties of the insulation materials. Damage can be general or localized. Service temperature is an important property as illustrated by [Figure 1.4](#), which shows the effect of temperature on the corrosion rate of insulated carbon manganese steel and introduces the concept of a closed system in which oxygenated water evaporation is limited, resulting in increased corrosion rates at higher temperatures. This is the reason why CUI is such a problem—corrosion rates are often greater than anticipated.¹⁴

In order to deal with and mitigate CUI, strategies must be developed that involve many competencies in the plant such as corrosion inspection, nondestructive evaluation, risk and safety evaluation, maintenance, unit operators, and plant management. These strategies require the identification of zones and equipment at risk (examples shown in [Figure 1.5](#)). The risk analysis should consider the impact on safety, the environment, and the performance (reliability/availability) of the units.

1.1 Purpose of document

The European Federation of Corrosion (EFC) working parties WP13 and WP15 have produced this guideline on CUI to promote such a strategy. The guideline reflects a consensus approach to this corrosion problem between the main European refining, petrochemical, and offshore companies who have contributed to producing this document. It is a collection of current experience primarily from the onshore and offshore oil and gas industries.

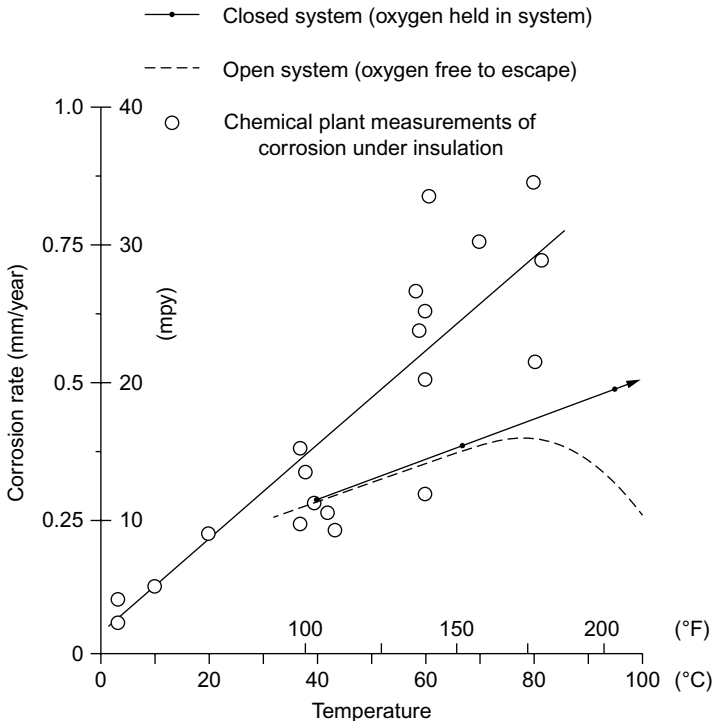


Figure 1.4 Corrosion rate as a function of temperature.

These companies included BP, Chevron-Texaco, Conoco-Phillips, ENI, Exxon-Mobil, IFP, MOL, Scanraff, Statoil, Shell, Total, and Borealis. The guidelines within this document are intended for use on all plants and installations that contain insulated vessels, piping, and equipment. Any CUI evaluation will require detailed knowledge of the plant and the site where the equipment is located as significant geographical differences between plants will have to be taken into consideration. CUI cannot be visually detected during normal service without removal of the insulation. Detailed knowledge/familiarity of systems, insulation characteristics, and the overall objectives of management expectation of systems are essential together with continuity of an adopted strategy.

The intent of the document is to provide the basis of a unified approach to CUI management and will incorporate risk-based methodology whenever possible. The problems associated with CUI will be defined and will include the financial aspects of CUI. It must be stressed that in order for this approach to succeed, it is important that both ownership and responsibility is clearly defined and demonstrated by management.

The primary objective of this document is to provide the background to manage CUI effectively using a high level risk-based approach to develop adequate inspection and maintenance strategies, using current Best Practices developed in the field. It is not intended that the document should provide a detailed prescription of when to inspect for CUI or to specify which of the many available nondestructive testing examinations or techniques (NDE/NDT) to use or to specify a particular maintenance



Isolated CUI in the center of a pipe



Localized CUI leading to metal perforation and leakage



CUI at insulation support ring



CUI at pipe support detail



CUI adjacent to vessel manway



CUI of vessel nozzle

Figure 1.5 Examples of CUI damage to carbon steel piping and equipment.

strategy. Guidance will be given on the most appropriate approaches to use, but the final decision will be left to the incumbent personnel who are responsible for the equipment that is susceptible to CUI.

The sections in the document will therefore include guidance on the following:

- Cost analysis
- Policy
- Strategy
- Inspection and maintenance

- Implementation
- Improvement

The different sections of this document and their relationship to the above concepts are shown in [Figure 1.6](#).

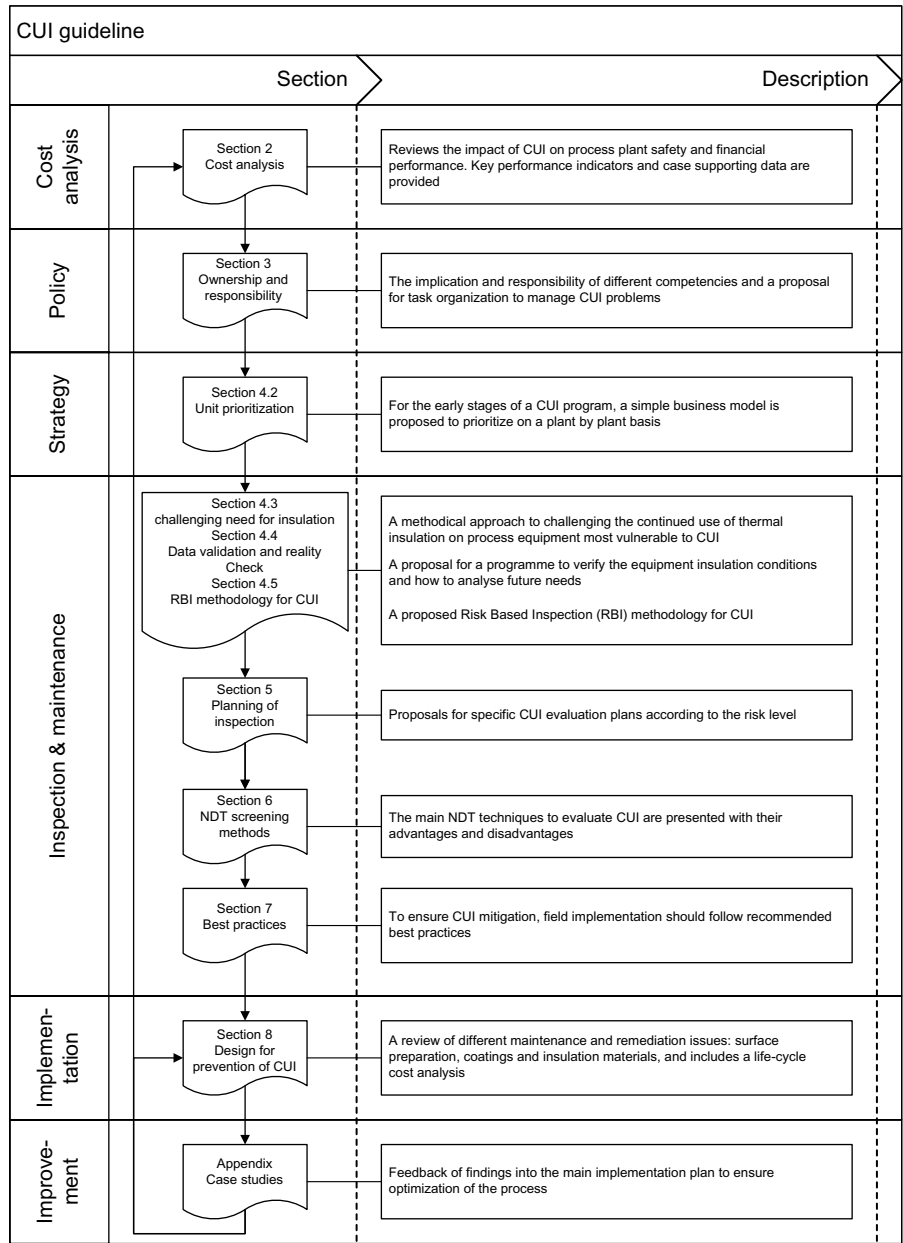


Figure 1.6 Schematic diagram showing the different sections of the guideline and their relationship to the different concepts in the document.

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Economic consideration

2

A fundamental step in the management process of any CUI or external corrosion control program is a rigorous review of the current plant status. This review should include steps to identify the current incident rate and potential incident rate, the impact of any failures on process plant safety, and the environmental and financial performance. A clear demonstration of the benefit to be gained vs. the potential cost of maintaining the status quo is a key driver in ensuring senior management support for what can be a significant investment program in any refinery or petrochemical, offshore, or other process facility.

2.1 Statistical analysis

Analysis of inspection advice notes or recommendations, maintenance work orders, and historical records should be carried out to determine a base case for failures and potential failure due to CUI or external corrosion. This information is best presented as an annualized figure, thus allowing year-by-year comparisons. Further partition of this data can prove useful in assessing the business risk ranking of process units used in high-level prioritization.

The number of CUI events that led to a loss of containment or leakage is the first key statistical figure. Each one of these events is likely to have significantly contributed to a lost profit opportunity for a process facility as sometimes they result in unplanned down time.

The number of CUI and external corrosion events that led to an additional engineering or maintenance work requirement is the second key statistical figure. While each one is less likely to have a significant contribution to the lost profit opportunity, as down time can be better managed and planned, they are a clear indicator of the underlying trend of CUI on the facility.

2.2 Size of the issue

There are many ways of quantifying the cost associated with CUI and external corrosion. When collecting the data to make such an analysis it is important to consider every detail, however small, as the cumulative effect will have a significant impact over the life of a facility.

Key factors to be considered are discussed below.

2.2.1 Safety and integrity

It is difficult to assign a cost to the safety impact of CUI or external corrosion in such an evaluation. However, it should always be the number one priority and any event that has a personnel safety impact should be scored appropriately.

CUI damage leading to a loss of containment of hydrocarbon gases and/or liquids, or the release of poisonous and otherwise dangerous gases and/or liquids (e.g., hydrogen sulfide, ammonia, etc.) will have very high associated costs if any personnel are injured and if there are fatalities.

2.2.2 Environment

Environmental impact would include unscheduled flaring, noise, losses to drains and water courses, air or soil pollution, and noncompliance with environmental regulations.

In recent years, any breach in environmental regulations has resulted in severe penalties to operating companies. In addition to these penalties, the reputation (also see [Section 2.2.4](#)) of the involved companies has suffered extensively.

2.2.3 Revenue or production loss

The costs associated with any CUI or external corrosion event which impacts production rate or product quality should be calculated. Most facilities run a linear model for production and this should be used in conjunction with the mid-cycle margin to calculate a production revenue loss. The evaluation should account for the volume of product lost, requiring reprocessing, or being downgraded. By using the mid-cycle margin one can remove the influence of fluctuating margins on a year-by-year basis when fixing lost profit opportunities against operating and maintenance budgets.

2.2.4 Reputation

Reputation may be considered to be a soft and internal company issue. However, it is a major company issue as its impact may outweigh the sum total of all other costs. Also, a potential loss of reputation may result in potential restrictions on a company's license to operate.

The total lost profit opportunity (LPO) for a facility is the sum of all of the above. Typical examples are quoted in the case history section.

It is important to remember that damage to a company's reputation will have a negative impact on shareholder confidence, directly influencing a company's overall value.

2.2.5 Collateral damage cost

If a process line or piece of equipment failed because of simple leakage and no other event occurred, then costing is simply the replacement cost of that item. If, however, another event occurred as a result of that leak, such as a fire, and other equipment was damaged then this must be accounted for in the evaluation. In some circumstances, environmental or cleanup costs should be considered and these may be significant.

2.2.6 On-line leak sealing cost

In certain situations it may be acceptable to contain a leak or potential leakage area within an on-line leak sealing device. Each device will have an associated manufacturing and installation cost. However, hidden behind this there may also be the cost of risk assessment to fit such a device and this should not be forgotten.

2.2.7 Repair/replacement, fabrication, and installation costs

Repair and/or replacement of corroded equipment and piping are maintenance or project costs depending upon the value of the item to be repaired or replaced. Emergency or replacement (reactive) repairs are often performed as part of an unplanned outage. If items can be deferred to a period of planned maintenance or project activity by using restricted fitness for continued service criteria, then it is important to capture these costs also. These costs should be annualized from the time of the evaluation up to the next planned outage period.

2.2.8 Fitness for continued service

The cost of evaluating whether it is safe to leave an individual item of externally corroded equipment in service, is not small. Based on the second key statistical figure referred to above, the value is likely to be large for a plant which has a high incidence of CUI or external corrosion.

2.2.9 On-stream inspection and NDE/NDT

Care must be taken with this value as only costs associated with a loss of containment, associated collateral damage, or those inspections associated with a specific external corrosion or CUI event which warrants an inspection advice note or recommendation should be captured.

2.3 Key performance indicators

With any program in which statistical evaluation of events and financial performance is used as a method of enhancing justification, it will benefit the project cycle if key performance indicators (KPIs) can be identified and used.

In CUI programs, the statistical KPIs could include, but are not limited to, the following items:

- Number of leaks due to CUI or external corrosion.
- Number of repairs for CUI or external corrosion.
- Number of CUI saves (capturing equipment and piping before wall loss becomes significant).
- The risk reduction produced when an item is mitigated against CUI by inspecting and maintaining (remove insulation, inspect, blast, paint, reinsulate, and seal).
- Reprioritization of inspection due dates.

In CUI programs, the financial KPIs could be items such as:

- LPO as a result of CUI or external corrosion.
- Maintenance repair cost due to CUI or external corrosion.
- Ranking of CUI or external corrosion in the facility revenue worst actors listing.

Ownership and responsibility

3

Everyone who is working in a plant is responsible for ensuring that insulated systems are correctly installed, inspected, and properly maintained. In addition to this, all personnel that are working in the plant are responsible for reporting damage to insulation systems when observed.

3.1 Senior management

Management should be aware of the problem of CUI and act such that both financial and human resources are available to manage the risk of CUI to an appropriate level. Management should also ensure that there is a culture within the organization that reinforces the need to treat insulated systems in a way that avoids unnecessary damage that would promote CUI.

3.2 Engineering manager

It is the responsibility of an engineering manager to revise and improve specifications and quality assurance/quality control for all vessel details, insulation, surface treatment, and supports and attachments to equipment in order to prolong the service life of equipment.

3.3 Maintenance

It is the responsibility of maintenance departments to ensure that insulated systems are correctly installed and maintained (painting and insulation) using approved standards and that adequate quality checks are carried out. The responsibility of avoiding damage to insulation through plant engineering work lies with maintenance departments. The inspection and corrosion engineering function should ensure correct maintenance procedures and check their execution.

3.4 Operations

The operations department should ensure that damage to insulation or steam tracing leaks under insulation are reported immediately to the maintenance department for repair. The responsibility of avoiding damage to insulation through plant operational

work lies with operations department. This includes any changes required to equipment following processes outside the operating window or when temporarily out of service (mothballing).

3.5 Inspection

Inspection departments should carry out inspection work to locate CUI on insulated systems, assess the degree of corrosion damage, and determine whether continued safe operation is affected. This function should also ensure that equipment or piping is repaired or replaced where required. Ensuring that proper standards of painting and insulation are applied, should be achieved through inspection. Inspection should also be undertaken during construction of new projects and plant changes.

3.6 Members of a project team: CUI program

Where a recognized ongoing CUI prevention program is not in place and lack of maintenance has led to poor condition of the insulation of equipment, a number of major organizations have resorted to setting up dedicated CUI project teams to address the issues of CUI. These teams may need considerable short-term funding to reinstate the refinery/process plant to an acceptable condition.

The risk-based inspection methodology for CUI

4

4.1 Introduction

The risk-based inspection (RBI) methodology for setting up inspection plans (Figure 4.1), which focuses most of the effort on those items that possess the highest risk of failure, is generally accepted in the refining, petrochemical, and offshore industries. For this reason, a similar approach is recommended for CUI.

The RBI assessment makes use of actual operational and structural conditions of insulated systems, not the design conditions. In order to obtain valid information from the RBI analysis it is important to be sure that all input data is correct. To this effect, data validation is described in Section 4.3, which is aimed to prevent errors in determining the risk of CUI failure. It should be noted that in some cases, especially in older plants, all input data cannot be verified without performing some inspections. Uncertainties should, therefore, be noted during the RBI assessment and verified during execution of the inspection plan.

When introducing the RBI approach, risks will not be known. Insulated systems will have to be assessed in order to determine the appropriate risk levels and the associated inspection plans. In large refining and petrochemical sites it will be impossible to conduct such an assessment on all insulated systems at once because of limited resources and budget. For that reason, a high level (unit) prioritization step is introduced that may help to determine the order of the RBI efforts. Using this approach, one will generally be able to initially direct RBI efforts to those insulated systems that feature the highest risks for operations. Section 4.3 will address this unit level prioritization approach.

Once the process units have been prioritized with respect to risk of CUI failure, it is recommended to carefully challenge the need for insulation. It is fairly obvious that the best way to eliminate CUI is to eliminate insulation (Section 4.4 discusses the requirement for insulation). The RBI assessment is resource intensive and it is acknowledged that a semiquantitative RBI assessment will not be possible or cannot be justified in all cases. Section 4.5, therefore, describes two RBI methodologies (qualitative and semiquantitative) with increasing complexity and accuracy.

To obtain valid, high quality data needed for a reliable RBI assessment (either qualitative or semiquantitative), the experience and knowledge of all the integrity management disciplines (Operations/Process, Inspection, Maintenance, and Corrosion) are needed for the “RBI team.”

The RBI assessments consist of a condition assessment of insulated systems, a risk level determination according to probability of CUI failure and consequence of CUI failure, and the resulting CUI inspection plan based on that risk level.

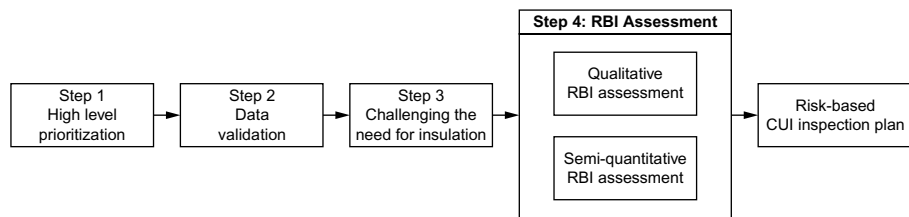


Figure 4.1 The four steps for developing a risk-based CUI inspection plan.

Once established, the inspection plan is used to periodically assess the condition of the insulated systems; the frequency and extent of the inspection efforts will depend on the risk level determined. Future inspection results shall also be used to reassess the initial risk level, which might lead to an adjustment of the risk level and, consequently, to a less or more intensive inspection scheme. The CUI inspection plan will also initiate maintenance tasks depending on the condition encountered.

In summary, it is recommended that when applying the RBI methodology to CUI it should be performed in four steps as shown in [Figure 4.1](#).

4.2 High-level prioritization

As with any cross facility program it is often difficult to identify where to start to gain the maximum benefit within an acceptable time frame. The program can take several years to complete one cycle and the available resources and budgets are often limited, even with senior management support. Identifying the areas of the process plant which are at risk from CUI and which have a big impact on health, safety, environment, and business is fundamental to the success of the initiative.

The RBI methodologies, as discussed in detail in [Section 4.5](#), are used to evaluate in detail the probability and consequence of a potential failure and thus provide a guide to inspection priorities and schemes. However, in the early stages of a CUI control program a qualitative screening model based on consequences of failure can offer a way to prioritize on a plant-by-plant or unit-by-unit basis.

The qualitative screening model described below is one example of deriving a priority plan for a given program. It is based upon a subjective assessment of plant condition and knowledge of process unit interactions. Users may wish to tailor the model to suit their own needs by applying different weighting factors for their own particular facility. An example of the spreadsheet used to make an assessment is shown in [Table 4.1](#).

The consequence of CUI failure categories are described as follows.

4.2.1 Health & safety consequences (A)

In this category the potential for injuries is assessed. Does a failure due to CUI put plant personnel or the general public at risk from a toxic release? Does a failure due to CUI put the plant or plant personnel at risk from a flammable or explosive release?

Table 4.1 Specific example of a unit level prioritization assessment

Unit name	Consequence of CUI failure				Total consequence to business A + B + C + D
	Health & safety A	Environmental B	Economic C	Impact on reputation D	
Process unit 01	7	7	7	7	28
Instrument air/fuel gas	7	3	7	7	24
Process unit 04	3	7	7	7	24
Process unit 05	1	7	3	0	11
Utility steam unit	3	1	7	0	11
Process unit 02	3	3	3	0	9
Process unit 03	3	3	1	0	7
Utility water	1	1	3	0	5

- High consequence (score=7)
 - Release of hydrocarbon gases and/or liquids
 - Release of poisonous and otherwise dangerous gases and/or liquids (e.g., hydrogen sulfide, ammonia, etc.)
- Medium consequence (score=3)
 - Steam leaks in areas with medium-to-high personnel densities
 - Leaks of nonflammable/nonpoisonous gases (nitrogen, etc.)
 - Leaks of corrosive chemicals (acids, etc.)
- Low consequence (score=1)
 - Nonflammable liquids
 - Nonpoisonous liquids
 - Water systems

4.2.2 Environmental consequences (B)

In this category the potential impact of a failure due to CUI on the environment is assessed.

- High consequence (score=7)
 - Large impact on the environment, extending outside the plant or facility borders
 - Affects neighbors or local communities
- Medium consequence (score=3)
 - Impact on the local environment inside the plant
- Low consequence (score=1)
 - No or very low impact on the environment
 - Spills can be safely collected and disposed

4.2.3 Economic consequences (C)

What is the economic consequence of a failure (e.g., extent of shutdown and costs of repair) due to CUI, on the specific process unit or plant being assessed?

- High consequence (score=7)
 - Complete shutdown of the plant/site
 - Loss of production >1 day
 - Capital replacement of equipment
 - For example, loss of process unit 1 would affect all downstream units if alternative feed-stock were not available. Loss of the steam raising plant would shut down a site that was heavily dependent on steam for heating and primary turbine drivers.
- Medium consequence (score=3)
 - Limited or partial shutdown of the plant/site
 - Reduced production capacity or loss of production <1 day
 - Extraordinary maintenance costs
 - For example, loss of the units that provide steam and fuel gas would affect the facility balance.
- Low consequence (score=1)
 - Single unit shutdown
 - Leaking or damaged equipment can be isolated

- No impact on continued operation of the plant
- Maintenance/replacement costs within maintenance budget
- For example, the unit does not affect the operation of other units, but may impact final product quality or available volume

4.2.4 Impact on reputation (D)

Does a failure due to CUI have an effect on the plant and/or company's reputation? Some incidents will not involve high costs, but could be regarded intolerable by the public and/or the authorities.

- High consequence (score = 7)
 - CUI failure affects plant and/or company's reputation
 - For example, failure receives adverse national or international media attention
- Low consequence (score = 0)
 - Plant and/or company's reputation is not affected
 - No media coverage

In the qualitative screening model described, the total consequence of failure (COF) is derived from the sum of the consequence factors A–D.

Once the scores have been sorted from high down to low, a review of potential synergies between adjoining plants should be conducted to adjust the proposed schedule. Similarly, the scheduled shutdown or inspection and testing plans should be reviewed to assess whether there are any potential clashes or missed opportunities for progressing the CUI control program.

4.3 Data validation

4.3.1 The need for data validation

For older plants there is often a mismatch between plant data and reality. It is, therefore, recommended to validate available plant data before conducting any RBI assessment for CUI.

Data validation should consist of two steps:

- Desk validation of available data
- Validation of data in the field

In the first step, information can be gathered from hard-copies (e.g., P&ID's, isometric- and other drawings, line- and equipment lists) and digitally from plant data systems (e.g., SAP, Ultimo, etc.). The next step is to validate this information in the field.

Data validation can be resource intensive and time consuming. For large plants, it is recommended to perform such validations according to the ranking obtained from the Unit Level Prioritization as described in [Section 4.2](#).

4.3.2 *Different aspects of a data validation*

It is critically important to check that operating conditions, not design conditions are recorded and used in the RBI assessment. Examples of aspects to challenge in data validation are:

- The necessity for thermal insulation of lines and vessels (as described in [Section 4.3](#)).
- That the system information provided is CORRECT (pipe metallurgy, wall thickness, actual presence of thermal insulation, actual presence of coating/paint, actual wetting frequency).
- That the operational conditions are CORRECT (surface temperature, possible cyclic conditions, whether it is actually in continuous/intermittent use).
- The actual system condition (based on inspection history; remaining wall thickness, coating/paint condition, condition of insulation system).
- If the insulated system is to be retired, then it should last for that required period which has to be taken into account when performing the risk analysis and determining the inspection and maintenance actions.
- If the vessel/piping is mothballed or otherwise out of service, then it may be unreasonable to devote time and money to assessing or refurbishing it.

4.3.3 *Implementation of data validation*

The simple process described below is one example of doing data validation. Users may wish to tailor the process to suit their own needs by including or excluding certain aspects such as mentioned in [Section 4.3.2](#).

The data validation process could be initiated within a project team as described in [Section 4.3](#) so that tasks can be assigned with clear responsibilities. Also, the scope of work for a desk validation is different from an on-site or field validation and may well be executed by different people. Also, on-site validation requires more resources and budget and is likely a part of an investment proposal.

Each insulated item appearing on the pre-screen list shall be visually checked for. For example:

- Insulation system presence:
 - Is the equipment or piping system insulated as expected?
 - Has the insulation been removed and not replaced?
- Item metallurgy:
 - Can this be verified?
 - Is it possible to examine flanges to determine item metallurgy or would PMI at a later stage be required?
- Item surface temperature:
 - Can the item surface temperature (under insulation or where bare) be measured?
 - How does the measured temperature compare to expected surface temperature based on process conditions?
 - Make sure the item is in stable service when measuring temperatures.
- Item exposure to cyclic service
- Item service condition:
 - Is the item in service?
 - If out of service, is it temporarily out of service or permanently?

A sample data validation list with examples is presented in [Table 4.2](#).

Table 4.2 Example of a data validation check list

Identifier	Insulation system present?	Metallurgy	Service conditions			CUI probable?
			In service?	Surface temperature (°C)	Cyclic service	
C-1001	Yes	CS	Yes	112	Yes	Yes
12"-1210-P1	Yes	SS	Yes	39	No	Yes
TK-231	No	CS	Yes	102	No	No
TK-401	Yes	CS	Yes	40	No	Yes
E-1400	Yes	AI	Yes	83	No	Yes
C-1203	Yes	CS	No	18	No	Yes
E-1603	No	SS	Yes	243	No	No

4.3.4 CUI and mothballing of equipment

Equipment is taken out of service with the intention of either permanent retirement (scrapping), or reuse after a period (possibly with refurbishment) due to operational need in cyclic service. In both cases the equipment and piping must be rendered safe and hydrocarbon-free. While permanent retirement can be considered a net loss, in the other case the equipment is important for the future of the plant and investment in a good mothballing procedure is critical. Specific mothballing procedures are required that preserve the equipment for future use and prevent any associated deterioration. In cyclic service a specific requirement for prevention against CUI is critical. Much equipment is not inspected for CUI due to the temperature range. Industry wide the range for CUI is estimated as between -4 and 175°C (carbon and low alloy steel). However, out-of-service equipment will also deteriorate under ambient conditions due to constantly saturated wet insulation which is not dried during the process cycles. As a consequence, even good quality low salt insulation will produce an accelerated corrosion rate when continually in contact with carbon and low alloy steels. This effect should be recognized during the data validation process, in which equipment and vessels which are out of service have to be assessed for CUI risks. A unit being out of service for only a few months will not have a great effect on the long-term (40+ years) viability of the average carbon steel or low alloy unit. However, after 12 months lying idle the unit's risk shall be assessed and scored accordingly.

4.4 Challenging the need for insulation

Dramatic increases in energy costs during the 1970s have resulted in a tremendous drive in the refining and petrochemical industries to conserve process energy, thus resulting in the increased, and in many cases excessive, use of thermal insulation. There is a need to challenge the very use of thermal insulation in the fight against CUI. This is, however, a difficult task as there will always be strong arguments not to remove any insulation from an operating plant.

The purpose of this section of the guidelines is to provide the user with a methodical approach to challenge the continued use of thermal insulation on the process equipment most vulnerable to CUI. The methodology described is also graphically presented as a decision flow diagram in [Figure 4.2](#).

Plant equipment and piping are insulated for any or a combination of the following reasons:

- Heat conservation
- Process control
- Freeze protection/winterization
- Personnel protection
- Noise control (acoustic purposes)
- Fire protection

This information is often contained in the equipment and piping specifications for a particular facility, and it may be useful to gain an understanding of the various insulation codes used in the relevant specifications.

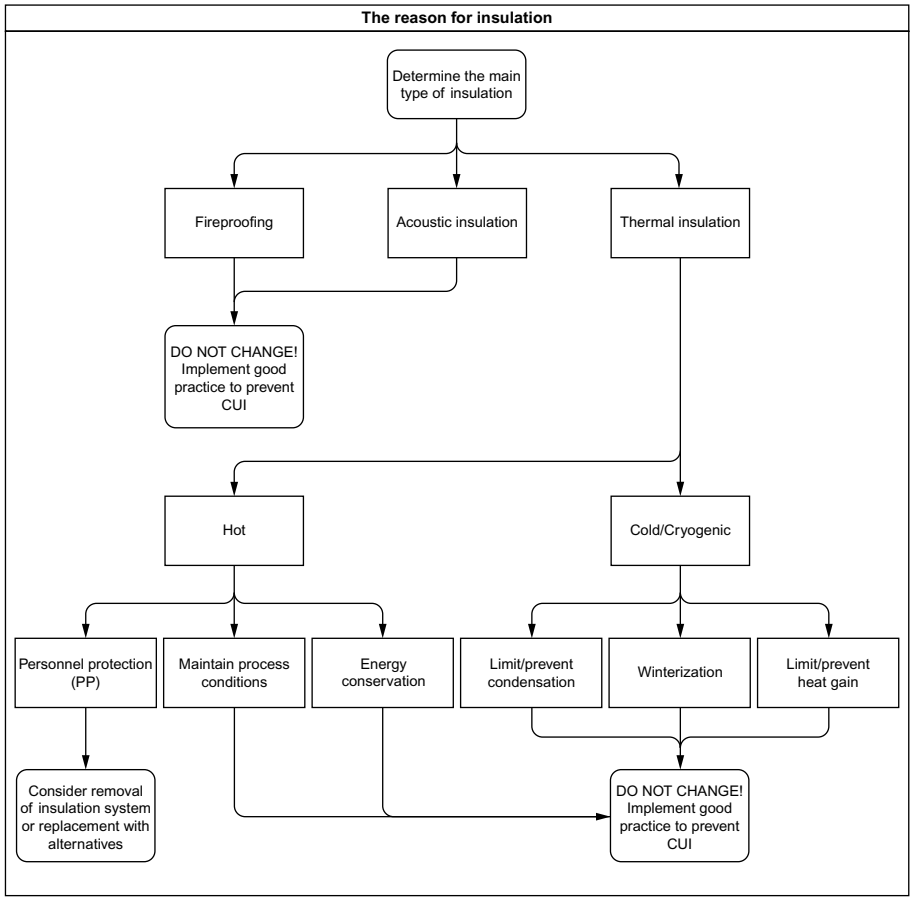


Figure 4.2 Challenging the need for insulation by understanding its purpose.

It is recommended that the use of thermal insulation for freeze protection or winterization as well as fire protection should not be challenged as these form a part of the safety design of a plant that should not be compromised. For such systems, all the recommendations for protection against CUI contained in this guideline should be implemented.

All thermal insulation used for personnel protection should be considered for removal and replacement with alternatives. Screens or protection bars may be used—see Appendix D. It may also be possible to use insulating coatings (ceramic coatings that reduce the surface temperature).

4.5 Using RBI to design CUI inspection plans

The RBI methodology, regardless of complexity or sophistication, uses consequence of failure and probability of failure to determine the risk of failure. In a conventional

RBI approach, the probability of failure is generally derived from corrosion rates obtained from inspections (wall thickness measurements) or corrosion model predictions, which can be used to estimate the remnant life of an item. However, the probability of a failure for CUI is difficult to determine because the corrosion rate is usually unknown and/or highly unpredictable. There are quite a number of factors that play a role in the process of CUI. The probability of CUI failure can, therefore, be assessed by considering different susceptibility factors, of which the operating temperature and the external environment (wetting extent and frequency) are the most important.

Many companies will have general probability and consequence factors well established in their systems. The aim of this section is not to replace these, but to give an example of the methodology of RBI for CUI.

Plants or facilities that do not have the resources to conduct a semiquantitative RBI analysis may opt to perform a qualitative RBI analysis.

4.5.1 Preparation of an RBI analysis

An RBI analysis starts with compiling detailed Asset Integrity Data for the unit under study. The Asset Integrity Data should be verified as described in [Section 4.3](#), and should ideally consist of the following:

- Process data, including actual operating windows.
- Engineering/design data and information on actual structural condition (see [Section 4.2](#)).
- A compilation of inspection history and degradation analysis.

For the sake of efficiency, the unit under study is divided into smaller corrosion loops or circuits, which are sections of the unit that are operating under similar conditions, are exposed to specific corrosion phenomena, and consist of similar materials.

4.5.2 Susceptibility factors

Score tables can be used to determine the level of CUI or CI-ESCC susceptibility. In the susceptibility tables, weighted scores can be awarded to a number of factors, which should include at least the key factors “operating temperature” and “external environment (wetting extent and frequency).” In this guideline, these key factors have been supplemented by five other factors contributing to the susceptibility to CUI (a total of four for CI-ESCC). The user may decide to change or add to the susceptibility factors in order to fit specific conditions. The six susceptibility factors used in this guideline are explained below.

4.5.2.1 Operating temperature

This is a very important aspect of an item’s susceptibility to CUI. In cyclic service (or temporary temperature changes), the temperature range corresponding to the most critical temperature reached should be taken.

For carbon and low alloy steels CUI seldom occurs below -4°C or above 175°C . Cyclic service conditions that might enter into this temperature range need to be taken into account when doing an assessment.

The occurrence of CI-ESCC below 60°C is very rare and as a conservative approach 50°C is used in this guideline. Above 175°C CI-ESCC is seldom found; however, the item may still have a high susceptibility as it will be exposed to the most vulnerable temperature range of $50\text{--}175^{\circ}\text{C}$ during startup or shutdown. The frequency of such temperature cycles should be taken into consideration.

4.5.2.2 *Coating status*

The coating is the main barrier between the steel surface and its environment. Therefore, the condition of the coating is crucial. Coatings degrade generally as a function of age, the older the coating the greater the probability of CUI. It should always be remembered that a poorly applied coating system can be worse than no coating at all, because it can accelerate corrosion by concentrating the corrosive effect on areas of coating breakdown.

Equipment construction should be reviewed in detail to identify areas which, by design or poor fabrication, can act as a trap for water resulting in coating breakdown. This will result in accelerated corrosion and an increased likelihood of both CUI and CI-ESCC.

4.5.2.3 *Cladding/insulation condition*

Although new cladding/insulation systems should be dry and virtually water tight, experience shows that, with age, water ingress is unavoidable. Mechanical damage, complex insulation geometries, and/or inspection windows will increase the chances of water ingress. In [Table 4.3](#) an example of an insulation deficiency/defect checklist is given that will assist maintenance and inspection staff with assessing insulation damage that might lead to CUI.

4.5.2.4 *Available corrosion allowance*

Thin-walled components will fail sooner due to a certain CUI corrosion rate than will thick-walled components. However, the risk of CUI failure will not primarily be determined by the wall thickness, but by the available corrosion allowance. Although generally a conservative measure, the corrosion allowance indicates the tolerance of the component to wall loss before it will fail. By adding corrosion allowance, the susceptibility to CUI will not change, but the susceptibility to CUI failure will get lower.

It is important to discriminate between the susceptibility to CUI, which is the chance that CUI will actually occur, and the susceptibility to CUI failure, which indicates the chance that CUI will lead to a failure; the latter is being considered here.

For instance, in the case that a small bore connection in certain conditions will end up in a high risk class, consideration may be given to replacing it with a similar connection with a higher schedule (thicker wall, more corrosion allowance), which will reduce the point score of the CUI susceptibility table.

Table 4.3 Example of an insulation deficiency and/or defect check list

Insulation defect	Tick if applicable
Caulking or sealant that has hardened and separated Circumferential cracks in glass-reinforced epoxy or glass-reinforced polymer jacketing Corrosion of cladding Damaged or loose cladding Damaged vapor barrier or stop Failure at bends (open joints) Foot traffic damage Gaps due to uncontrolled expansion or contraction Hot or cold spots Icing and/or condensation Incorrectly installed at flanges or valve boxes Longitudinal cracks in glass-reinforced epoxy or glass-reinforced polymer jacketing Missing insulation (not reinstalled after maintenance activities) Missing insulation at flanges or valve boxes Missing self-tapers, rivets, or stainless steel bands Rust stains and bulges in metal cladding Sagged insulation and cladding No termination at flanges or valves No termination in a vertical pipe or piece of equipment Water increase at penetration (e.g., nozzles)	

4.5.2.5 External coil/steam tracing

The presence of steam tracing adds to the susceptibility to CUI because it may start leaking and thus provide a source of water for the corrosion process. The susceptibility score depends on the integrity of the steam tracing system for which the following three factors are considered:

- Coil corrosion in resistant material (copper, high alloys, e.g., Alloy 800, 825, etc.).
- Coil installed using the highest level of quality control (e.g., 100% visual and leak test).
- Heating medium is controlled and of good quality (noncorrosive/erosive).

High integrity design means that all of the three aspects are satisfied. Mean integrity design means that only two out of the three aspects are satisfied. Low integrity design means all other systems.

4.5.2.6 External environment

For CUI to occur, water needs to penetrate the insulation material and contact the metal substrate surface. The degree of water ingress depends on the condition of the insulation material and the water sources and can be from rainfall, climatic environmental operating conditions, cooling water drifts, firewater, deluge systems, etc.

Where no water can enter the system (inside buildings, no steam tracing, no sweating, etc.), the susceptibility to CUI will be insignificant and, therefore, the risk can be set to negligible by default.

4.5.3 Qualitative RBI analysis

As with any cross facility program it is often difficult to identify where to start to gain the maximum benefit within an acceptable time frame. One cycle of a semiquantitative RBI program can take several years to complete, and the available resources and budgets are often limited, even with senior management support. A qualitative RBI analysis can be used to relatively quickly prioritize units on a site or equipment and line items within a unit on risk (criticality). Such a simple, qualitative criticality assessment is mainly based on Consequence of failure (CoF) and a limited probability of failure as described in this section. As will be discussed, a CoF assessment is usually sufficient for a first prioritizing indicating the highest criticality items.

To start the RBI assessment for each unit, a list needs to be developed that contains equipment and piping items (or groups of piping items) that are susceptible to CUI. The initial susceptibility to CUI can be based on metal temperatures during operation, using the following criteria:

- Insulated carbon- or low alloy steel operating in the temperature range -5 to 175°C .
- Insulated austenitic stainless steel (e.g., 300 series stainless steels) operating in the temperature range 50 – 175°C .
- Insulated equipment or piping in cyclic service where the metal temperatures will cycle into or through the above temperature ranges.

Once a list of susceptible equipment and/or piping has been compiled, the assessment starts with a high level CoF analysis. For this, the RBI team can use the consequence assessment method described in [Section 4.2](#) (High-level prioritization) or use one of the consequence matrixes shown in [Tables 4.5, 4.7, 4.11, and 4.12](#).

Because the objective is to obtain a prioritized list of equipment and line items in a short time, the assessment can stay at a higher level (in case of doubt assume conservative, no need to spend too much time on details). Despite the need for some conservatism, the RBI team can take credits for factors that can limit the damage. For example, the release of a highly poisonous gas in a congested area will have a higher chance of multiple fatalities than if it is released at a location where personnel are seldom present.

The next step is the CUI probability assessment. However, when looking at the risk matrix provided in [Figure 4.3](#) it becomes clear that with an “extreme” and “high” CoF the criticality basically remains “high” to “extreme” unless the probability of CUI is “negligible.” In other words, when an item is classified as a “high” or “extreme” CoF, a quick probability assessment just to check that the CUI probability is not “negligible” (e.g., the item was not relatively recently reinsulated with high quality CUI mitigation in place) is usually sufficient. In such cases it can be more efficient/cost effective to schedule complete replacement of the coating and insulation system, and repair or even replace the equipment, than embarking on a detailed CUI probability assessment or even a Semiquantitative RBI analysis.

Probability class	H	L	MH	H	E	E
	M	L	M	MH	H	E
	L	N	L	M	MH	H
	N	N	N	L	M	MH
		Negligible	Low	Medium	High	Extreme
		Consequence class				

Figure 4.3 Qualitative CUI risk.

For items with a lower CoF, the probability assessment discussed later and/or a more detailed RBI assessment (Semiquantitative RBI analysis) can be executed followed by defining inspection and maintenance activities/strategies as described in [Section 4.5](#).

The follow-up actions also depend on the confidence of the RBI team in the RBI results. As emphasized previously in [Section 4.5.1](#), it is important that the data used for RBI is verified and reliable. For prioritizing, identifying the high criticality items based on CoF the lack of verified data usually is not an issue, but to define longer term inspection and maintenance strategies a higher confidence in the results is required. This can be achieved by using verified data.

The qualitative probability of failure can be determined using the susceptibility factors detailed in [Tables 4.4](#) and [4.5](#) for carbon- and low alloy steel, and in [Tables 4.6](#) and [4.7](#) for austenitic stainless steel. It should be noted that these scoring tables are indicative. Depending on local experience and site policies, different scoring tables might be required.

The qualitative probability of CUI failure assessment should be combined with a qualitative consequence of CUI failure assessment as described above.

The qualitative CUI risk can be determined using the risk matrix as shown in [Figure 4.3](#). The CUI inspection strategy for each of the risk categories is detailed in [Chapter 5](#).

4.5.4 *Semiquantitative RBI analysis*

Where semi- or fully quantitative RBI analyses are available either in-house or through commercially available RBI programs, these should be used as far as possible for the assessment of CUI. Users are cautioned against commercial RBI programs that attempt to calculate a corrosion rate for CUI. The probability of failure for CUI is difficult to determine because the corrosion rate is highly unpredictable and localized. It is best assessed using susceptibility factors, of which the operating temperature and the external environment (wetting extent and frequency) are the most important.

Table 4.4 CUI susceptibility assessment for carbon and low alloy steels

Susceptibility factor			Susceptibility class			
			N (score = 0)	L (score = 1)	M (score = 3)	H (score = 5)
Coating	No coating		–	<2 years	2–5 years	>5 years
	Organic coating	Poor-quality coating or hand surface preparation	–	<8 years	–	>8 years
		High-quality coating (immersion service) with good surface preparation	–	<12 years	Damaged coating <12 years	>12 years
	Thermal sprayed aluminum (TSA)	Surface preparation with no QA/QC	<12 years	–	–	>12 years
		Surface preparation with detailed QA/QC	<20 years	20–25 years	25–30 years	>30 years
Heat tracing			Not present	Present	–	–
Cladding/insulation condition			Good engineering standards Recently installed <5 years Preventative maintenance program	Good engineering standards 5–10 years Preventative maintenance program	Poor engineering standards 5–10 years Corrective maintenance	Poor engineering standards >10 years and/or system is visually in a bad state No maintenance
Local environment			Dry/indoors	Inland or mild industrial climate Rarely wetted: < 10% of the time	Moderate coastal or industrial climate Frequently wetted: 30% of the time; rain or high humidity	Severe coastal or offshore climate Almost permanently wetted (e.g., cooling tower vicinity condensation, dripping)

Table 4.5 Probability of CUI failure class carbon steel and low alloy steel

Probability of CUI failure class	CUI susceptibility score
N	0–2
L	3–4
M	5–9
H	>10

The aim of this section is not to replace existing probability or consequence assessments, but to give an example of the quantitative RBI methodology for CUI.

4.5.4.1 Consequence of CUI failure

The consequence modeling in full quantitative RBI systems tends to be very comprehensive and will provide a refined view of failure consequences.

Usually, a total of five consequence categories for economics, health & safety, and the environment are considered. However, this might be different for different operating companies. [Table 4.8](#) provides an example of assessed consequences.

4.5.4.2 Probability of CUI failure

When the consequence of failure has been established, the probability of failure is determined. This assessment should distinguish between carbon steel (CS) or low alloy steel, and austenitic stainless steel.

For austenitic stainless steel the term CUI refers to chloride external stress corrosion cracking (Cl-ESCC). Chlorides in the permeated water can, depending on the temperatures and concentration, cause external stress corrosion cracking in AISI type 300 series austenitic stainless steel. Cl-ESCC typically is found in stressed areas (such as welds), where chloride ions dissolved in water are in contact with type 300 series stainless steel at temperatures above 60 °C (temperature of 50 °C is used for guidance in this guideline).

The susceptibility to CUI or Cl-ESCC failure is taken as the indicator for the probability class. It is important to avoid attempts to calculate a corrosion rate as this can be highly inaccurate for CUI.

Score tables are used to determine the level of CUI or Cl-ESCC susceptibility. In the susceptibility tables, weighted scores can be awarded to a number of factors, which should include at least the key factors “operating temperature” and “external environment (wetting extent and frequency).” In this guideline, these key factors have been supplemented by five other factors contributing to the susceptibility to CUI (a total of four for Cl-ESCC). The user may decide to change or add to the susceptibility factors in order to fit specific conditions. The seven susceptibility factors used in the following example are explained in [Section 4.5.2](#).

An example of a susceptibility score table for carbon steel and low carbon steel is shown in [Table 4.9](#) and the one for austenitic stainless steel Cl-ESCC is shown in

Table 4.6 CUI susceptibility assessment for austenitic stainless steels

Susceptibility factor		Susceptibility class				
		N (score = 0)	L (score = 1)	M (score = 3)	H (score = 5)	E (score = 13)
Coating	Organic coating	–	–	<5 years		>5 years or damaged or porous coating
	Thermal sprayed aluminum (TSA)	<10 years	10–20 years	20–30 years		>30 years
Aluminum foil (austenitic stainless steel only)		<8 years		8–10 years		>10 years
Cladding/insulation condition		Good engineering standards Recently installed <5 years Preventative maintenance program	Good engineering standards 5–10 years Preventative maintenance program	Poor engineering standards 5–10 years Corrective maintenance program	Poor engineering standards >10 years and/or system is visually in a bad state Corrective maintenance program	
Local environment		Dry/indoors	Inland or mild industrial climate: Rarely wetted <10% of the time	Moderate coastal or industrial climate: Frequently wetted 30% of the time; rain or high humidity	Severe coastal or offshore climate: Almost permanently wetted	

Table 4.7 Probability of CUI failure class for austenitic stainless steel

Probability of CUI failure class	CUI susceptibility score
N	0–2
L	3–5
M	6–13
H	>13

Table 4.8 Example of consequence categories

Consequence category	Health & safety consequences	Environmental consequences	Economic consequences
Negligible	No/slight injury First-aid case and medical treatment case Not affecting work performance or causing disability	No/slight effect	No/slight damage No or very slight disruption to operations
Low	Minor injury Loss time injury Affecting work performance, such as restriction to activities or a need to take a few days to fully recover (maximum 1 week)	Minor effect	Minor damage Brief disruption to operations
Medium	Major injury Including permanent partial disability Affecting work performance in the longer term, such as prolonged absence from work Irreversible health damage without loss of life, for example, noise induced hearing loss, chronic back injuries	Localized effect	Local damage Partial shutdown that can be restarted
High	Single fatality Also includes the possibility of multiple fatalities in close succession due to the incident (e.g., explosion)	Major effect	Major damage Partial or complete operational loss

Table 4.8 Continued

Consequence category	Health & safety consequences	Environmental consequences	Economic consequences
Extreme	Multiple fatalities From an accident or occupational illness (e.g., chemical asphyxiation or cancer (large exposed population))	Massive effect	Extensive damage Substantial or total loss of operation

Table 4.10. Points should be awarded to each class, more points for higher classes. The points awarded to any class can be determined by the user and can be dependent on their specific conditions. By adding the point score of the contributing factors, the total probability score can be determined.

Using the total score from the susceptibility score table, a probability class can be determined. For CS/low alloy steel, as well as for stainless steel, four probability classes are used in this example (but the user may decide to use more or less probability classes):

- Probability class negligible (total score $1 - A$)
- Probability class low (total score $A - B$)
- Probability class medium (total score $B - C$)
- Probability class high (total score $> C$)

The limits A, B, and C have to be determined by the user based on experience and generally perceived corrosion rates in circumstances resembling the susceptibility conditions making up the total probability score.

It should be noted that the probability class, in combination with the consequence category, determines the risk level and hence there should be a sound relation with the inspection interval assigned to that corresponding CUI risk class. For instance, for a high risk item with a predicted corrosion rate of 0.5 mm/year and a corrosion allowance of 2 mm, the inspection interval should be significantly less than 4 years. However, for a low risk item in the same conditions an interval of 4 years may be acceptable.

4.5.4.3 Risk of CUI failure

Using the determined probability classes and the consequence categories, the CUI risk class can be established using a typical risk matrix such as [Table 4.11](#) or a risk matrix designed for CUI for CS/low alloy steel as well as stainless steel such as [Table 4.12](#). The risk assessment matrix or table can have any form depending on each individual company's philosophy, but must be consistent with the risk assessment procedures for other hazards.

Table 4.9 Example of a susceptibility score table for CUI of carbon and low alloy steel

Class	Susceptibility factors					Total CUI susceptibility score
	Operating temperature	Coating status when new or last applied	Cladding/insulation condition	External coil/steam tracing	External environment	
CS-1	Continuously below -4°C Or Above 175°C	Full QA coating <8 years Or TSA < 15 years	Good engineering standards Or Renewed (<5 years)	Not present	Inside building, not steam traced and not sweating Default negligible risk	
	?	?	?	?	?	
CS-2	$150-175^{\circ}\text{C}$	Full QA coating 8–15 years Or Conventional coating <8 years Or TSA 15–20 years	Average condition, overall high integrity design and construction	High integrity design	Low wetting rate (<20% of the time)	
	?	?	?	?	?	
CS-3	-4 to 49°C And 111 to 149°C	Conventional coating 8–15 years Or TSA > 20 years	Average condition, conventional design and construction	Medium Integrity Design	Medium wetting rate (20–50% of the time)	
	?	?	?	?	?	

CS-4	50–110 °C Or Sweating conditions	Coating > 15 years Or Unpainted Or Unknown	Poor condition, damaged, wet, or broken seals Or Insulation older than 25 years where there is a risk of extensive insulation material degradation	Low integrity design or leaking	High wetting rate(>50% of the time) For example, cooling tower/ deluge systems	
Score	? ?	? ?	? ?	? ?	? ?	?

Note 1: Dead legs shall be treated the same as main pipe, except that temperature should be estimated, because the dead leg will be much cooler, especially if long. For example, a dead leg on a 230°C line could easily be in the 50–110°C metal temperature range for high probability.

Note 2: In case of cyclic service (or temporary temperature changes), the range corresponding to the most critical temperature reached shall be taken.

Table 4.10 Susceptibility score table for austenitic stainless steel

Class	Susceptibility factors					Total CUI susceptibility score
	Operating temperature	Shop coating or aluminum-wrap status & age	Cladding or insulation condition	External coil or steam tracing	External environment	
SS-1	Continuously <50 °C Or >175 °C	Shop coating (full quality assurance) <8 years Or Aluminum-wrap <15 years	Good to engineering standards (undamaged)	Not present	Inside building Not steam traced Not sweating	
	?	?	?	?	?	
SS-2	>50 °C	Shop coating (full quality assurance) 8–15 years Or Maintenance coating <8 years Or Aluminum-wrap 15–20 years	Minor damage but with special precautions Special areas	High integrity design	Low wetting rate (<20% of the time)	
	?	?	?	?	?	

SS-3	>50 °C	Shop coating >12 years Or Maintenance coating >8 years Or Aluminum-wrap >20 years	Average condition; No special precautions Sensitive areas	Medium integrity design	Medium wetting rate (20–50% of the time)	
	?	?	?	?	?	
SS-4	50–175 °C Or Cyclic conditions	Shop coating >15 years Or Maintenance coating >12 years Or Unknown	Poor condition Severely damaged Wet or unknown	Low integrity design Or Leaking	High wetting rate (>50% of the time) For example, cooling tower or deluge systems	
	?	?	?	?	?	
Score	?	?	?	?	?	?

Table 4.11 Example of a generic risk matrix

Probability of failure (<i>F</i>)	Category	Consequence				
		A	B	C	D	E
<i>F</i> > 0.050	5 (Very likely)					
MTBF < 2	4 (Somewhat likely)				High	
<i>F</i> = 0.015						
MTBF = 7	3 (Unlikely)			Medium		
<i>F</i> = 0.01	2 (Very unlikely)		Low			
MTBD = 10						
<i>F</i> = 0.005	1 (Practically impossible)					
MTBF = 20						
<i>F</i> < 0.0025						
MTBF = 38						
Safety (instant visibility)		No injury	Minor injury	Medical treatment	Serious injury	Fatalities
Health (long-term visibility)		No effect	Minor impact	Temporary problems	Limited impact on public	Serious impact on public
Environment		No damage	Minor impact No response	Limited response	Significant response	Full-scale response
Economic loss (€)		<5 k€	5 k€–0.1 m€	0.1–1 m€	1–10 m€	>10 m€
Public disruption		None	Minimal	Minor	Small community	Large community

MTBF, mean time between failure.

Table 4.12 Example of a risk matrix to determine CUI risk of failure

Susceptibility to CUI failure			CUI risk class				
Probability Class	H	Total score > C	L	MH	H	E	E
	M	Total score: B – C	L	M	MH	H	E
	L	Total score: A – B	N	L	M	MH	H
	N	Total score: 1 – A	N	N	L	M	MH
Consequence class			Negligible	Low	Medium	High	Extreme
Consequence Category	Economics (€)		No/slight damage	Minor damage	Local damage	Major damage	Extensive damage
	Health & safety		No/slight injury	Minor injury	Major injury	Single fatality	Multiple fatalities
	Environment		No/slight effect	Minor effect	Localized effect	Major effect	Massive effect

Where N, negligible; L, low; M, medium; MH, medium high; H, high; E, extreme.

The final step is to link the determined risk class to the appropriate inspection and maintenance strategy. Distinction shall be made between strategies for CS/low alloy steel and stainless steel.

References

1. European Commission for the 'GROWTH Programme, Research Project RIMAP (Risk Based Inspection and Maintenance Procedures for European Industry)', GROWTH Project GIRO-CT2001-03008 'RIMAP', D4.2 Petrochemical Workbook, Document 4-43-F-2004-01-1, 2004, P. 27.

The intent of this section is to provide an overview of a sample inspection strategy that can be applied to all equipment (including piping) in addressing the problem of CUI. Individual companies may have their own strategies that they consider appropriate. The inspection plan or strategy applied is dependent on and interacts with the principles and results of [Sections 4.3 and 4.5](#). Removal of insulation, external visual inspection, and damage evaluation using a nondestructive examination (NDE) or non-destructive testing (NDT) are the key issues proposed. While nonintrusive techniques (perform NDE/NDT inspection without removal of insulation) may be used to assist the evaluation for corrosion, it is the general consensus of opinion in the refining and offshore industry at the time of this writing that none of the NDE/NDT methods available alone can provide an adequate level of confidence in their sensitivity to detect and quantify CUI. It is also known that CUI is often found at locations where it was not predicted. Although only visual inspection gives a 100% CUI indication, only focusing on typical locations as described in this chapter is not always reliable. A thoughtful consideration should be made before designing an inspection strategy about the scope of insulation removal. The techniques of on-stream inspection/renovation/refurbishment has now been well developed.

5.1 General considerations

There are several ways of detecting CUI on piping systems. Detecting CUI on vessels is generally more difficult, but it is possible using some techniques. Before selecting NDE/NDT for the detection of CUI, consideration should be given to the following:

- (i) The metallurgy (CS, SS, etc.).
- (ii) Operating conditions.
- (iii) Insulation type and thickness.

Selecting an NDT technique for detecting CUI also requires detailed knowledge of the piping system or equipment layout as well as the advantages and disadvantages with a cost/benefit ratio for each technique.

Highly suspect areas that should be considered for CUI inspection include penetrations and damaged insulation. These are detailed below: If (documented) history regarding insulation is missing or unreliable, for instance, repaired or refurbished insulation may be given a low CUI probability risk during inspection but moisture/water ingress during the previous situation could be overlooked. The choice of whether to focus only on critical locations or do a 100% insulation strip can only be made based on a thorough understanding of the pipe/equipment insulation history.

- *Penetrations*
 - All penetrations or breaches in the insulation jacketing systems such as dead legs, hangers and other supports, valves and fittings, bolted-on pipe shoes, ladders and platforms, and vessel nameplates attached by welding.
 - Steam-tracer tubing penetrations.
 - Termination of insulation at flanges and other components.
- *Damaged insulation areas*
 - Damaged or missing insulation jacketing.
 - Termination of insulation in a vertical pipe or piece of equipment.
 - Caulking/sealant that has hardened or separated, or is missing.
 - Bulges, staining of the jacketing system, or missing bands/screws.
 - Low points in systems that have a known breach in the insulation system, including low points in long, unsupported piping runs.
 - Carbon or low-alloy steel flanges, bolting, and other components under insulation in high-alloy piping.
- *Other areas*
 - Areas exposed to sources of water such as mist overspray from cooling towers; to steam vents; to deluge systems; or to process spills, ingress of moisture, or acid vapors.
 - Carbon steel systems, including those insulated for personnel protection, operating between -5°C and $+175^{\circ}\text{C}$.
 - Carbon steel systems that normally operate in service above 175°C , but are in intermittent service or are subjected to frequent outages.
 - Dead legs and attachments that protrude from the insulation and operate at a different temperature to that of the active line.
 - Systems in which vibration has a tendency to inflict damage to insulation jacketing, providing paths for water ingress.
 - Steam-traced systems experiencing tracing leaks, especially at tubing fittings beneath the insulation.
 - Systems with deteriorated coating and/or wrappings.
 - Cold service equipment consistently operating below the atmospheric dew point.

5.2 Typical locations on piping circuits susceptible to CUI

Piping systems may have specific locations that are more susceptible to CUI (Figure 5.1). These areas include the following:

- All penetrations or breaches in the insulation jacketing systems including:
 - Dead legs (vents, drains, etc.).
 - Pipe hangers and other supports.
 - Valves and fittings (irregular insulation surfaces).
 - Bolt-on pipe shoes.
 - Steam and electric tracer tubing penetrations.
- Termination of insulation at flanges and other piping components.
- Damaged or missing insulation jacketing.
- Insulation jacketing seams located on the top of horizontal piping or improperly lapped or sealed insulation jacketing.
- Termination of insulation in a vertical pipe.

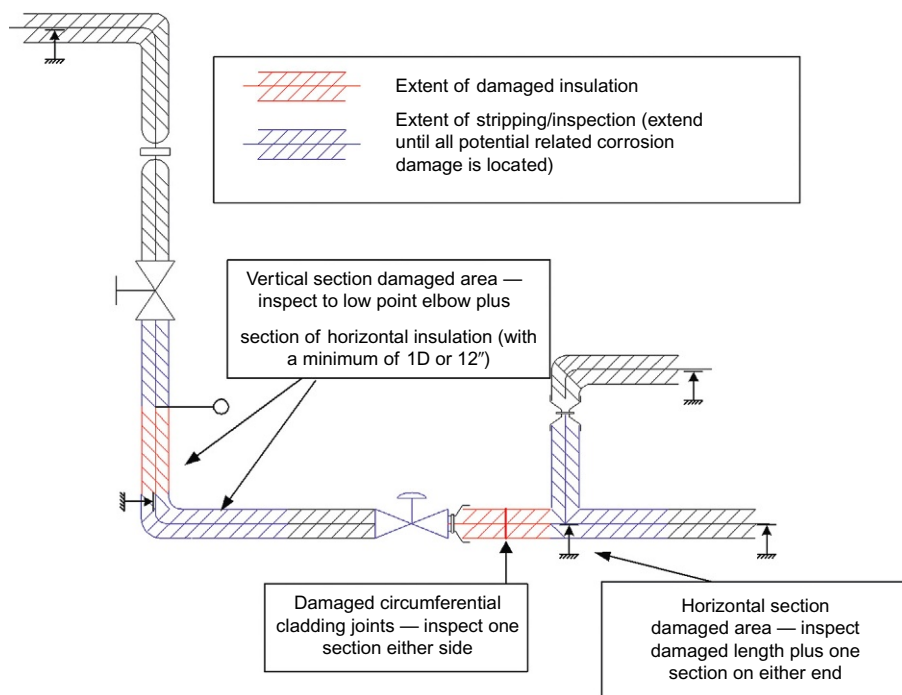


Figure 5.1 Example of piping areas of concern.

- Caulking/sealant which has hardened, separated, or is missing.
- Low points in piping systems that have a known breach in the insulation system, including low points in long unsupported piping runs.
- Insulated flange-pairs.
- Pipelines in trenches with poor sewerage function.

Particular attention should be given to locations where insulation inspection plugs have been removed to permit piping thickness measurements on insulated piping. These plugs should be promptly replaced and, if necessary, sealed.

5.3 Typical locations on equipment susceptible to CUI

5.3.1 Vessels, columns, and tanks

Specific areas of focus on pressure vessels (Figure 5.2), columns, tanks (Figure 5.3), and other insulated vertical equipment are detailed as follows:

- Termination of insulation at flanges.
- Insulation rings, particularly top and bottom heads of vertical vessels.
- Stiffening rings for vacuum design (vessel or column).
- Insulated skirt zone attached to items and about 0.5 m under the weld of skirt (vessel or column).

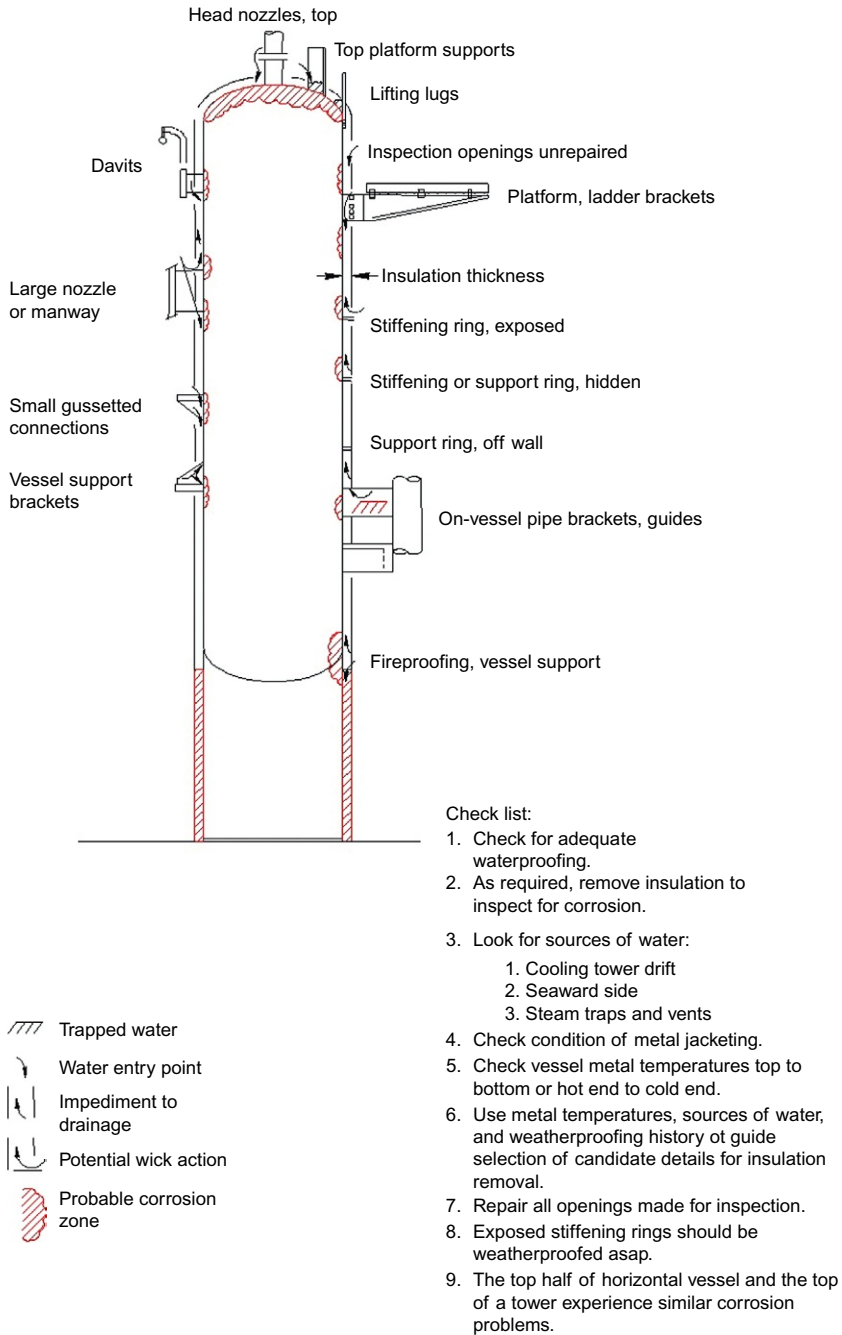
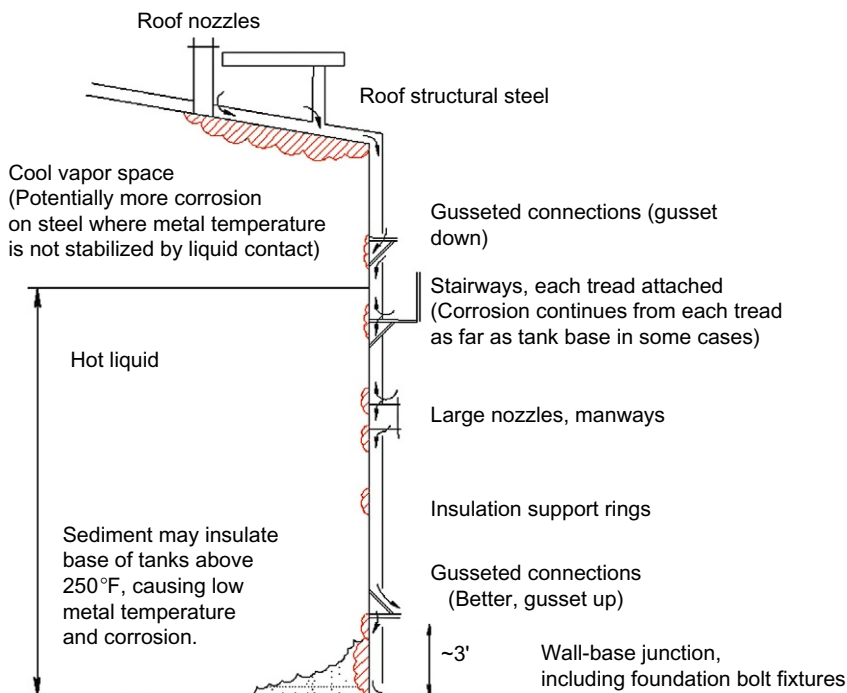


Figure 5.2 Example of vessel areas of concern.



General notes:

1. Water entering roof insulation can cause severe corrosion of walls as well as roof, where impediment to drainage exists. Seriously defective roof weatherproofing can quickly destroy a tank if metal temperatures permit.
2. prolonged flooding of tank area basin due to environmental restrictions on draining is a cause of severe corrosion around base of tank.
3. Routinely inspect weatherproofing and steel. Repair insulation damage resulting from inspection.
4. Weatherproofing and design corrections are essentially the same as for vessels, except for roof/wall joint.

Figure 5.3 Example of tank areas of concern.

- Insulated leg supports for small vessels.
- Damaged or missing insulation jacketing.
- External base ring of insulated tanks.
- Pipe and flange on pressure safety valve (PSV).
- Temporary insulation installations.

Particular attention should be given to locations where insulation inspection plugs have been removed to permit piping thickness measurements on insulated piping. These plugs should be promptly replaced and, if necessary, sealed.

5.3.2 Heat exchangers

Specific areas of focus on heat exchangers and other insulated horizontal equipment are detailed as follows:

- Termination of insulation at flanges
- Termination of saddles insulation
- Rings for insulation
- Damaged or missing insulation jacketing
- Pipe and flange on PSV

Attention should be given to locations where insulation inspection plugs have been removed to permit piping thickness measurements on insulated piping. These plugs should be promptly replaced and, if necessary, sealed.

5.4 Examples of risk-based inspection plans

The following examples provide an indication for the scope of inspection that is required when considering the likelihood of CUI. RBI should be used to minimize the economic impact prior to establishing ongoing CUI inspection and rehabilitation programs. A number of different methodologies can be employed in order to mitigate CUI. The selection will depend on the scale of any CUI, resources employed, and location/type of plant being considered.

- Individual targeted high safety/health/environment (SHE) risk equipment with known CUI issues.
- Individual targeted high economic risk equipment with known CUI issues.
- Individual high risk equipment with potential CUI issues.
- High risk equipment within a particular area (zone approach).

5.4.1 Evaluated risk level: High/extreme

- (i) 100% removal of thermal insulation.
- (ii) Complete visual inspection for corrosion and condition of coating as applicable (including dye penetrant or alternating current field measurement (ACFM) inspection to check for CI-ESCC of austenitic stainless steels).
- (iii) Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- (iv) Analyze for root cause considering critical points.
- (v) Reinstate using practices recommended in this document.
- (vi) Reevaluate the risk.

5.4.2 Evaluated risk level: Medium-high

- (i) Greater than 40% removal of thermal insulation including all critical points and damaged areas.
- (ii) Complete visual inspection of exposed areas for corrosion and condition of coating as applicable (including dye penetrant or ACFM inspection to check for CI-ESCC of austenitic stainless steels).

- (iii) Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- (iv) Analyze for root cause considering critical points.
- (v) Reinstall using practices recommended in this document.
- (vi) Re-evaluate the risk.

5.4.3 Evaluated risk level: Medium

- (i) Greater than 20% removal of thermal insulation including all critical points and damaged areas.
- (ii) Complete visual inspection of exposed areas for corrosion and condition of coating as applicable (including dye penetrant or ACFM inspection to check for CI-ESCC of austenitic stainless steels).
- (iii) Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- (iv) Analyze for root cause considering critical points.
- (v) Reinstall using practices recommended in this document.
- (vi) Reevaluate the risk.

5.4.4 Evaluated risk level: Low

- (i) Remove thermal insulation at all critical points with evidence of damage.
- (ii) Complete visual inspection of exposed areas for corrosion and condition of coating as applicable (including dye penetrant or ACFM inspection to check for CI-ESCC of austenitic stainless steels).
- (iii) Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- (iv) Analyze for root cause considering critical points.
- (v) Reinstall using practices recommended in this document.
- (vi) Reevaluate the risk.

5.4.5 Evaluated risk level: Negligible

No inspection is required when the evaluated risk level is negligible.

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Nondestructive examination and testing techniques for CUI

6

6.1 NDE/NDT techniques

The following NDE/NDT techniques can be used to detect CUI. A more comprehensive description of each technique is attached in Appendix A.

- External/visual inspection (with and without removal of insulation)
- Ultrasonic thickness measurement (with and without removal of insulation—includes through inspection openings)
- Flash radiography
- Guided wave ultrasonic
- Profile/flash radiography
- Digital radiography
- Real-time radiography
- Pulsed eddy current
- Digital/real-time radiography
- Infrared
- Neutron backscatter
- Dye penetrant testing

The limitations, advantages, and disadvantages of each technique are detailed in [Table 6.1](#). A comprehensive review of nondestructive evaluation techniques has been carried out by MTI¹ in 1998. This document provides a very thorough review of all the nonintrusive inspection methods available at that time; a summary is shown in [Tables 6.1 and 6.2](#).

Table 6.1 Limitations, advantages, and disadvantages of different NDE/NDT techniques for CUI

NDE/NDT technique	Limitations	Advantages	Disadvantages	Comments
External/visual inspection	Requires removal of insulation—“strip off and inspect”	Can see the problem—positively identifies all areas of CUI Can apply a range of tools to quantify the problem Gives confidence	- Expensive and requires other techniques to quantify metal loss - Cannot directly <i>measure remaining wall thickness</i>	The most effective inspection method If insulation is removed on a sample basis, may not strip off “worst areas” and may give false confidence
External/visual inspection without removing insulation	- Generally carried out as a first pass and is usually limited by access - Very easy to cut windows	Little cost for an initial evaluation	Only covers small areas, will only provide a guide to potential problem areas	Can be very effective for a first pass on an installation with a CUI program Windows can be a source of water ingress Generally not used for CUI
Ultrasonic thickness measurement through inspection openings	Only a very small area is inspected	It gives remaining wall thickness NB: UT measurements can be very effective for general CUI when taken internally	It can be difficult to obtain readings on a corroded surface	
Ultrasonic thickness measurement	Requires removal of insulation and limited by surface condition	It gives remaining wall thickness following external and internal corrosion	Can be difficult to obtain thickness readings on a corroded surface. Generally requires <i>surface grinding or brushing</i>	Used in conjunction with pit gauging

Profile radiography	Unlikely to detect CI-ESCC in stainless steels. Typically only a single orientation is used making it possible to miss localized thinning	It gives remaining wall thickness without removing insulation. Can be applied while equipment is running. Will reveal both internal and external corrosion thinning	Only for pipe wall in small sections SHE issues, test areas require barriers to restrict access. The exposure source is usually Iridium 192. Cobalt 60 is used for pipes of heavier wall, but the weight is about 250 kg Generally slow and suitable for pipe size <8"	One of the most effective methods, very good results achieved, often used to evaluate the suitability of piping for insulation removal and grit blasting
Digital radiography	Does not detect CI-ESCC in stainless steels. Typically only a single orientation is used, making it possible to miss localized thinning	As above—image management easier	Scaffolding required when using Co 60 for thick sections (heavy enclosures [about 250 kg]) More expensive than profile radiography	As above—provides greater flexibility when reviewing images Ongoing developments include SCAR/SafeRad, CMOS, Gamma-Scan RTR
Flash radiography	Setup requires at least 1½ days. It is utilized up to 1 m in diameter. This technique does not detect SCC in stainless steels	Film processing generally takes about 15 min No need to remove insulation	Contrast and resolution are not as good as that for conventional radiography. It can also be difficult to separate images from multiple exposures	

Continued

Table 6.1 Continued

NDE/NDT technique	Limitations	Advantages	Disadvantages	Comments
Real-time radiography (Lixi)	Does not detect CI-ESCC in stainless steels Thickness variations confuse interpretation	It is a fast and reliable survey method without need to remove insulation. Gamma-ray can give indication of remaining wall thickness. Can be applied while equipment is running	Radiography gives only the profile of outside pipe SHE issues, use of gamma-ray source test areas require barriers to restrict access. It gives video images which can be recorded for evaluation later Requires a considerable amount of manipulation to ensure adequate coverage	Technique shows promise although application slower than claimed
Real-time radiography (image scope)	Limited to small bore connections	No requirement to remove insulation	Only provides profile of pipe OD Requires a considerable amount of manipulation to ensure adequate coverage	Technique shows promise although application slower than claimed
Guided wave ultrasonic	This system does not detect localized corrosion and it gives percent wall thickness loss. Only for piping systems. This technique does not detect SCC in stainless steels	The probe ring is applied at large intervals of pipe (6–10 m) and the measurement itself is a matter of minutes compared to the total inspection time. Can be applied while equipment is running	Needs to remove insulation where the probe ring must be applied (about 200 mm). It is utilized only for pipeline. It is not used for vessel or tanks Results distorted by diameter of test component	Very expensive Noninvasive technique

Pulsed eddy current	This system does not detect localized corrosion including CL-ESCC in stainless steels The inspection area is limited Does not work through galvanized steel cladding This system does not detect CUI	Does not need to make contact with the surface Scaffolding can be reduced by using rope access or by attaching the measuring sensor to a straight pole Can be applied while equipment is running It provides temperature information to detect the presence of moisture or water in insulation. Can be applied while equipment is running	It is utilized for ferrous pipe, vessels, or tanks Results distorted by diameter of test component	Requires validation
Infrared		It provides accurate information on the presence of moisture or water on insulation. Can be applied while equipment is running	Must be utilized with another NDE/NDT system to verify CUI	Uses a screening tool. Developments ongoing using pulsed techniques
Neutron backscatter	This system does not detect CUI	It provides accurate information on the presence of moisture or water on insulation. Can be applied while equipment is running	Must be utilized with another NDE/NDT system to verify CUI	Moisture measurement relative
Dye penetrant testing following removal of insulation	Requires removal of insulation and any protective coating	It gives indications of pitting or surface breaking SCC	Very slow Mainly used for austenitic stainless steel Surface condition dependant—may not always detect fine cracking on heavily corroded surfaces	Prevention is the preferred solution for CI-ESCC

Table 6.2 Overview of capabilities and limitations of methods demonstrated during MTI project 118

	Radiation						Electromagnetic		Ultrasonic		
	Tangential			Through transmission							
	Neutron	Gamma	X-ray	Film digitizing	Solid-state detector	Profiling	Pulsed eddy current	Encircling coils	Single L modes	Multiple L modes	SH modes
Wet insulation effects	Severe	Some	Some	Some	Some	Some	None	None	Some	Some	None
Effect of pipe being water filled	Severe	Some	Some	Some	Some	Some	None	None	Some	Some	None
Inspect elbows?	P	Y	Y	Y	N ^a	Y	P	N	N	N	N
Inspect vertical pipe?	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y
Inspect under hangers?	N	N	N	N	N	N	N	N	Y	Y	Y
Inspect across penetrations?	P	Y	Y	P	N	N	N	N	P	P	P
Detect discrete defects?	N	N	N	Unknown	Y	Unknown	N	Y	Y	Y	Y
Detect wall thinning?	N	N	N	Unknown	Y	Y	Y	Y	Y	Y	N
Detect OD damage?	N	Y	Y	Unknown	Y	Y	Y	Y	Y	Y	N
Detect ID damage?	N	N	N	Unknown	Y	Unknown	Y	Y	Y	Y	Y

Inspect stainless pipe?	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y
Inspect through Galvanized jacket?	Y	Y	Y	Y	Y	Y	P	P	Y	Y	Y
Inspect through Stainless jacket?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Inspect across wires/straps	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y
Pipe inspected ft./8 h day ^b	500	500	500	20	250	1000	90	120	80	60	60
Operator skill ^c	B	I	I	I	I	I	B	A	A	A	A
Development ^d	C	C	C	C	C	A	A	E	A	E	E
Global (G)/local (L)/scanning (S)	L	S	S	L	S	S	L	S	G	G	G
Surface access required	N	N	N	N	N	N	N	N	Y	Y	Y

Y: Method can achieve.

N: Method cannot achieve.

P: Method can partially achieve.

^a A two-dimensional array of these detectors is now available for film style through transmission radiography, and robotic improvements are under way to allow inspection of vertical pipes and elbows.

^b This is only an estimate and is only for the test used in this program. Many methods will inspect more pipe with fewer penetrations and bends. Set-up time for the relatively short amount of pipe in the test also comprises a larger portion of time than if thousands of feet were to be inspected. The amount of pipe inspected in the field will be different. The field-ready techniques are typically faster than the emerging technologies. Some methods will be misrepresented because they are spot measurements that were used to perform full body scanning.

^c B: Basic (high school and on-the-job training); I: intermediate (e.g., Level II equivalent); A: advanced (bachelors degree or higher).

^d C: Commercially available; A: advanced stage of field testing/commercial very soon; E: entry level field testing.

References

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Recommended best practice to mitigate CUI

7

7.1 Background

In order to ensure that the field implementation of a “best practice” insulation specification is successful, care must be taken in the development and design of all components of the specification. Deficiencies in any one of the components can and do lead to premature failure of the insulation “system.” Next to the design of the insulation system, the choice of insulation materials and the application is of paramount importance.

What are the primary parameters that control the effectiveness of an insulation system? What is the key parameter that controls life expectancy?

7.1.1 Key parameters

Field experience from a wide variety of oil, gas, and petrochemical companies has indicated that the following parameters are important:

- Insulation selection.
- Protective coating selection.
- Weather barrier selection and design.
- Service temperatures (“cold” or “hot” insulation or dual temperature).
- Local environment.
- Equipment/piping insulation design details.
- Installation procedures.
- Inspection and maintenance practices.
- Life-cycle costs (LCC).

Historically, greater emphasis has been placed on the type of protective coating, type of insulation, and type of weather barrier to be selected with less emphasis on the installation and maintenance of the insulation system. Failure of the insulation system is relative. Often the weather barrier is the first to fail, followed by gradual degradation of the insulation and the protective coating, leading to “hidden” localized corrosion of the steel equipment beneath the insulation.

7.1.2 Assumptions

How is failure defined?

Failure is relative because it is associated with a number of components in a multicomponent system. It is often assumed that the weather barrier is impermeable to water or moisture ingress. This is not always the case. The external weather protective

claddings are not intrinsically waterproof following commissioning or after startup. Whether this situation remains as such depends on the maintenance strategy. But a weather protective cladding is never a moisture barrier and so it should be assumed that moisture and water can penetrate the external weather barrier immediately after installation.

A second assumption is that the insulation material cannot and does not “hold” water. This, again, is not necessarily true because the extent of water retention is a function of the type of insulation being used; water can be retained by all insulation materials. CUI has been associated with all the different types of insulation materials that have been employed.

A third assumption is that the protective coating employed resists aqueous corrosion—again this is not always true. The life expectancy of coatings ranges from 2 to 25 years (and even greater in some circumstances) with an average expectancy of less than 10 years.

For the majority of the oil, gas, and petrochemical companies, failure is usually defined when leakage to the atmosphere occurs as a result of metal perforation.

The previous assumptions are true for carbon steel installations. Chloride stress corrosion cracking of austenitic stainless steels, although less typical, is another failure definition.

7.2 Current CUI prevention methods

It is the current oil, gas, and petrochemical practice to include most or all of the following conventional CUI mitigation methods:

- Design and install the insulation system to exclude water ingress.
- Apply suitable organic protective coating to resist corrosion.
- Perform periodic visual inspection and/or nondestructive inspection (NDE/NDT) activities.
- Periodically strip all insulation, prepare surfaces for coating, and reinsulate.
 - Maintenance of a conventional coating system (paint) is the only mitigation for CUI on carbon steel equipment.
 - Conventional paint systems have an average life expectancy (9–13 years)¹ that is heavily dependent on proper surface preparation and application.
 - Cold service equipment prevents maintenance of conventional paint systems without unit shut-downs.

7.3 How to achieve a life expectancy of over 25 years

The rate of corrosion is influenced by the service conditions, the local environment, and by the design details. The rate of corrosion is also influenced by the installation practices and by the local inspection and maintenance practices. These all affect the total cost of the installation (i.e., the LCCs).

So what is the key parameter that controls the life expectancy of an insulation system and what is required to ensure a life expectancy of more than 25 years?

It is now believed that the key parameter that controls the life expectancy of an insulated system is the protective coating. Failure of the weather barrier due to inadequate design, installation, or maintenance will lead to water ingress and retention. Subsequent degradation of the barrier coating leads to corrosion. The selection of a coating and a “fit-for-purpose” insulation system is, therefore, the key to the success of the insulation system as a whole. Many types of coating systems are available but the selection criteria must include the following in order to be economically viable and effective. In other words, consider the following:¹

- The lifetime of the equipment—include both the internal and the external corrosion mechanism and corrosion rates. Typically, a plant life expectancy in excess of 25 years for equipment is generally used as the basis for all economic evaluations. Consideration of shorter periods can be adopted when the remnant plant life is limited. The majority of refining equipment in use today is considerably older than 25 years as essential refineries were initially installed during the 1950s and 1960s. Construction of petrochemical, gas, and hydrocarbon processing plants and offshore production facilities continue, however, to the present day.
- The cost of application and reapplication of the protective coating and insulation system over the lifetime of the equipment.
- The expected lifetime of the protective coating system—this has consistently fallen short of all expectations.
- The cost of inspection and maintenance for insulation.

Appendix C provides more information on the many types of protective coatings that are available. However, the coating that is most likely to provide effective corrosion protection for over 25 years is thermal sprayed aluminum (TSA). It is, therefore, recommended that where a minimum design life of 25 years is required TSA should be considered for the protective coating of all new equipment and should always be considered for the protective coating of equipment subject to maintenance and rehabilitation work. The following sections provide more detail on the benefits of TSA which will provide a low-cost, leak-free system for well over 25 years. The application of conventional paint systems have a life expectancy heavily dependent on proper surface preparation and application (see [Table 7.1](#)).

7.3.1 CUI preventive measures: Recent approaches

The following CUI prevention or mitigation strategies have been developed in order to prolong the life of all insulated equipment. They maintain a lower failure potential over a longer life cycle and are, therefore, not as dependent on the effective but expensive maintenance and inspection activities that are required to manage CUI.

- Application of TSA coating system
- Upgrading to stainless steel when economically justified
- Removing unnecessary insulation
- Removing insulation at pipe support vents, etc., with a seal on either side to remove the water ingress point
- Use of Al foil to prevent CI-ESCC
- Use of waterproof/imperious nonmetallic weather protection barriers

Table 7.1 CUI prevention on-line field application—TSA and paint

Features	TSA	Conventional paint
CUI protection	25–30 years; maintenance-free; inspection-free	5–13 years; tends to low side for on-line application
Protection in cyclic service	Yes	No effective paint system
Upper continuous operating temperature	480 °C (If a seal coat is not applied)	Typically 175 °C (up 540 °C with specialist paint systems)
Schedule impact	None—one coat application (If a seal coat is applied then same cure required as for paint)	24 h typically; multiple coats required
Environmental impact	None (for seal coat, same as paint)	Must meet VOC and disposal regulations
In-place cost ratio	1.05–1.20	1.0
Durability	Very resistant to mechanical abuse. Minor damage does not result in CUI	Very susceptible to mechanical abuse. Any damage likely results in CUI
Required surface preparation	White/near white (SA 2½)	White/near white (SA 2½)
Application method(s)	Twin arc spay or flame spray (for seal coat—same as for paint)	Spray, brush, and roller
Application accessibility	Arc/spray head to within an angle of 30° normal to surface	Brush/roll for restricted access but life decreases
Application temperature limit	None but service must be dry unless applying seal coat	Ambient to about 60 °C
Work permit required	Hot work	Cold work, but it can restrict hot work in the area where painting is taking place

7.3.2 Material upgrade possibilities

The methodologies for CUI mitigation include:

- Painting/coating carbon and austenitic stainless steel for protection.
- Application of TSA.
- A metallurgy upgrade from carbon manganese steel to an austenitic or duplex stainless steel.

While CUI of carbon steel is a relatively slow process, austenitic stainless steels are susceptible to accelerated corrosion (particularly CI-ESCC) if exposed to wet aqueous conditions containing chlorides. Failures of insulated austenitic stainless steels by pitting and stress corrosion cracking due to chlorides have been extensively reported. Duplex stainless steels are less susceptible but are not totally immune. However, provided suitable precautions are taken (especially when considering cold service insulation), stainless steels can prove to be more economical than carbon steels if LCCs are considered.

In order to minimize the risk of chloride SCC, the use of duplex stainless steels should be considered for operating temperatures greater than 50 °C. The upper temperature limit at which duplex stainless steels can be used will depend on the actual grade selected. A temperature of 120 °C is typically used for the generic 2205 duplex stainless steel. The appropriate specialist engineers must carefully review each application before proceeding. The greatest savings can be made for:

- Small diameter piping systems.
- Equipment requiring cold service insulation.
- Equipment that will be operating under cyclic conditions.
- Equipment that will be operating in high humidity environments.

Because it will often be possible to reduce or eliminate corrosion allowances when moving from carbon to stainless steel, significant savings can often be made in terms of total weight and cost by specifying thinner schedules. Although duplex stainless steels have a greater cost than austenitic stainless steels, advantage can be taken of the higher mechanical properties of duplex stainless steels in order to reduce the thickness of equipment further.

This can be illustrated by considering piping purchased according to ASTM A312/A79 and calculating the maximum allowed pressure at 90 °C (200 °F) according to ASME B31.3 (Table 7.2),^{2,3} shows how the allowable pressure increases as the grades of stainless material is increased.

For an application that would require a Sch40S type 304 piping to contain the design pressure, a Sch10S duplex stainless steel pipe would most probably suffice. Obviously, calculations based on the actual design parameters need to be carried out. These should also include other factors such as piping stresses, etc.

Pipe thickness reduction will not only save on direct material cost, but also lead to lower costs and savings when considering:

- Welding (i.e., lower labor, less supervision and welding material costs).
- Lower total weight (i.e., lower cost for scaffolding, handling, etc.).
- Indirect savings due to lower instances of leaks.
- Safer operation.

Table 7.2 Allowable stress comparison

	Nominal 1" diameter piping [barg (ksi)]	Nominal 2" diameter piping [barg (ksi)]	Nominal 3" diameter piping [barg (ksi)]
TP304L Sch40S	219 (3.18)	137 (1.98)	130 (1.88)
TP304 Sch40S	263 (3.81)	163 (2.37)	155 (2.25)
SAF 2304 Sch10S	296 (4.29)	159 (2.31)	118 (1.71)
SAF 2205 Sch10S	319 (4.62)	171 (2.49)	127 (1.84)
SAF 2507 Sch10S	372 (5.39)	200 (2.90)	148 (2.15)

Not every application will show an economic incentive. The costs depend on the availability of the material, the process environment, operating temperature, etc. However, the LCC principle should be used to determine the actual impact on overall costs of a project and not only on the initial installation costs alone.

7.4 Benefits of TSA

The cost of a protective coating system that is being applied beneath an insulation system should include the total cost of installation and the total costs involved in the maintenance and inspection of the system over the entire life of the system.

The main advantages of TSA coatings over conventional organic coatings include:

- Longer life expectancy with minimal requirements for maintenance and inspection.
- Resistance to mechanical damage.
- Greater range of temperature resistance than organic coatings (–100 to 500 °C).
- Provides sacrificial protection to steels in aqueous environments.

The main disadvantages of TSA coatings over conventional organic coating include:

- Higher cost of application.
- Increased difficulty of field application.
- Resistance to change by operations and maintenance organizations.

Provided that the total LCCs of operating a piece of insulated equipment are taken into consideration, the application of TSA, as a protective corrosion resistant coating can be more effective and more economic than using an organic coating. The costs that should be included are:

- Cost of surface preparation.
- Cost of coating application.
- Cost of field erection (if new equipment) or extra costs if field applied.
- Cost of inspection and quality assurance.
- Cost of in-service inspection.
- Cost of in-service maintenance.
- Cost of repair/replacement in the event of CUI.

7.5 Use of personnel protective guards

Removal of insulation stops CUI and the associated inspection and maintenance costs. With the use of personal protection guards (see Appendix D) instead of insulation, savings of up to 100% of the costs associated with CUI incidents can occur, which can help to quickly recover the installation cost of the personal protection guards.

Traditionally, personal protection consists of insulating the pipe work to prevent human contact with hot surfaces. This is an easy option and is predominately applied because other methods are seen as more expensive and requiring more resources. With

business needs driving efficiency improvements in maintenance and capital spending, the initial cost of personal protection is as important a factor as LCCs. Use of personal protection guidelines will reduce initial costs as well as improve life cycle savings.

Possible savings include:

- 100% of the cost of CUI (pipe replacement, painting, and insulation).
- 10–20% on initial costs compared to thermal insulation.
- 90% or more on future pipe inspection costs.

A number of UK and European Standards are available,^{4,5} which give more detailed guidance for the design of guarding for personnel protection against heat exposure. They are utilized for equipment or pipelines whose surface temperature is above 60 °C. Each guard shall be individually designed for its specific duty and local service conditions.

- Guards and their supports shall be manufactured from carbon steel, which may be galvanized or painted (the mesh may be painted with black and yellow stripes, 50 mm wide, and shall include a hazard sign indicating “Hot Surface”).
- The guard mesh shall be 12 mm square when the distance from the heat source is less than 40 mm, and can be a maximum of 40 mm square when the distance from the heat source is >180 mm. The guards shall extend to a height of not more than 2 m above or 600 mm beyond areas at ground level or on platforms, access ways, stairways, ladders, and other positions of personnel access for operational purposes.
- Guards may be supported by the pipeline or equipment they are protecting. They shall have the support clamp(s) painted with the same paint system as that specified for the pipeline.
- Guards shall be securely anchored and not distort if leaned against. They shall be free from sharp edges.
- All guarding shall be of a permanent type, designed to withstand mechanical abuse.

7.6 Use of aluminum foil to mitigate CI-ESCC of austenitic stainless steel

As discussed earlier, the first reported instance of CI-ESCC on austenitic stainless steel was published in 1965.⁶ Since then many articles have been published reporting similar instances but without guidance of how to mitigate the problems. Many companies and contractors currently use aluminum foil to prevent CI-ESCC of austenitic stainless steel piping and vessels. The use of aluminum foil to mitigate CI-ESCC was first published by ICI in 1985.⁷ When applied as recommended it has been shown to be 100% effective in preventing CUI due to chloride stress corrosion cracking. Concern over possible liquid metal cracking of austenitic stainless steels has been expressed; however, a literature search did not highlight any instances of aluminum initiating liquid metal cracking. Cost comparisons in both North America⁸ and Europe showed that the cost of Al-foil wrapping was 60–80% of the conventional coating cost. Discounted cash flows of 40% or greater will be typical.

The use of aluminum foil is recommended for all austenitic stainless steel piping requiring CUI chloride stress corrosion cracking protection on all maintenance

and capital projects.⁹ Typically, austenitic stainless steels can be used economically for small-bore piping replacing small-bore carbon steel piping failing from CUI. Aluminum foil can also be used on austenitic stainless steel vessels in lieu of conventional coating for Cl-ESCC cracking protection—costs should be economically based.

The use of aluminum foil in sweating service requires a considered reappraisal because service life of aluminum-foil will be shortened. TSA is recommended in sweating service.

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Design for the prevention of CUI



8.1 Introduction

Equipment and piping design has an important influence on CUI. If proper consideration is given to CUI at the design stage, it may be possible to eliminate corrosion altogether, or at least significantly limit the potential for CUI and CI-ESCC. It is the intention of this chapter to give a brief overview of what designers should consider and some examples of good design practices that will reduce the potential for CUI and CI-ESCC.

It is not the intention here to provide an in-depth, detailed description of all design aspects relating to CUI prevention. Reference can be made to the CINI Handbook (Insulation for Industries)¹ for explicit details relating to insulation design. NACE SP0198 (Standard Practice; Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A Systems Approach)² provides important details of mechanical features of vessels, tanks, and piping systems that should be considered to prevent CUI and CI-SCC.

There is some overlap with other sections of the document, particularly regarding materials used for insulation, weatherproofing, and coating, and using life-cycle costing. The reader is, therefore, recommended to refer to these other sections for additional information.

8.2 Challenge the requirement for insulation

The best way of avoiding CUI is not to fit insulation at all. [Section 4.4](#) provides detailed information on how the need for insulation can be challenged. Ideally, this decision should be correctly made at the design stage. Insulation is required for many reasons such as process requirements, heat conservation, fire protection, noise, preventing freezing or condensation, personal protection, environmental challenges, energy savings, etc. However, experience has shown that sometimes the level of challenge has not been sufficient when deciding whether insulation is required and this has resulted in insulation being fitted when it need not have been. Where insulation is required only for personal protection it is better to fit metal guards rather than insulation.

8.3 Plant layout

When designing where to situate equipment and piping, consideration should be given to providing sufficient space to allow effective inspection and maintenance in the plant. For example, experience has shown that pipes placed too close together are practically impossible to effectively inspect and maintain. Piping crossing too closely to each

other will make the effective application of good insulation system principles difficult, and often provides breaches in insulation systems that ultimately result in CUI.

8.4 Mechanical considerations: Equipment and tanks

Equipment and tank design and mechanical details have an important influence on the potential for CUI. There are many undesirable design features that influence CUI, some of which are:

- Using shapes that are likely to retain water, such as flat horizontal surfaces, vacuum rings, and insulation support rings.
- Using shapes that are impractical to insulate and weatherproof effectively, such as gussets and I-beams.
- Using shapes that funnel water into the insulation, such as angle-iron brackets.
- Other items that cause interruption in the weatherproofing, such as lifting lugs, ladder brackets, nozzle extensions, and decking and platform supports.

The more breaks there are in the weatherproofing, the more likely it will be that water will enter the insulation and potentially cause CUI. It is, therefore, essential to minimize the number of nozzles, supports, and fixings that will protrude through the weatherproofing. Due to the difficulty in weatherproofing and sealing vessel lifting brackets, it has become a good practice to cut these off once the equipment has been lifted onto the plant and securely fixed in position.

Some further examples of good practice include the following:

- Hand railings on insulated tank roofs should be installed at the side of the roof edge instead of on top of it.
- Fixings on insulated tank walls and roofs should be cylindrical rather than angled steel, to avoid retention of water.
- Angle steel used for vacuum rings on columns should be installed with the outer vertical edge downwards to allow water to drain off.
- Nameplates on insulated equipment should not interfere with the insulation and weatherproofing, they should be fitted on short brackets so that the nameplate does not extend beyond the weatherproofing. A duplicate nameplate can be mounted on the outside of the metal jacketing for in-service identification.
- Insulation support rings on vessels can be designed with a gap between the support ring and the vessel outer wall. More details can be found in NACE SP0198.
- Collars on top side nozzles.

8.5 Mechanical considerations: Piping

As for equipment and tanks, the more breaks there are in the weatherproofing, the more likely it will be that water will enter the insulation and potentially cause CUI. It is, therefore, essential to minimize the number of vents, drains, supports, flanges, and fixings that will protrude through the weatherproofing.

Pipe supports are a common cause of CUI due to the difficulty in insulating and properly sealing around them. Rod hangers or clamps used to support piping by “direct contact” are impractical to insulate and seal effectively against water ingress. Another support that is similarly difficult to insulate is the flat beam support, where the piping directly rests on a flat metal beam.

All insulated piping should, therefore, be designed with suitable pipe supports that mitigate, or at least minimize water ingress. It is considered a good practice to use high-density insulation at support locations and fit load bearing supports that will contact the weatherproofing only, thus enabling a continuous weather barrier.

Some examples of further good practices include the following:

- Locating valves and flanges in the horizontal part of piping runs rather than the vertical to limit water penetration and retention.
- Providing enough space between piping and adjacent piping or plant structural supports to enable effective inspection and maintenance *in situ*.
- Not placing insulated piping in trenches or drains below grade due to the potential for immersion in water if the drains are not kept clear.
- Clamped pipe shoes should be avoided in critical CUI areas and only welded shoes should be used to avoid points of entrapment.
- Insulating vertical pipe support, hangers, vents, valve-spindles, etc., using conical end caps (Chinese hat) or covers, which preclude rainwater.
- The use of water detection devices at lower of critical spots that act as a warning for water.

8.6 Materials of construction

Carbon and low alloy steels are the most common materials of construction for equipment, tanks, and piping. When insulated, these materials often suffer from CUI in the form of localized or general corrosion. The potential for CUI is influenced by several factors including operating temperature, the potential for water ingress into the insulation, etc. If the risk of CUI is considered very high for, say, carbon steel, the designer may select another material of construction that will not suffer from CUI (e.g., austenitic and duplex stainless steels, accepting that there may still be a risk of CI-ESCC). The designer may even select high nickel alloy materials that are practically immune to both CUI and CI-ESCC.

Naturally, when selecting more costly materials of construction at the design stage, it is important to consider life-cycle costing over the design life of the project, to provide economic justification for selecting these materials.

8.7 Coatings and wrappings

Coatings and wrappings applied to the external surface of equipment, tanks, and piping are the last line of defense in preventing CUI. Generally speaking, organic coatings, thermal spray aluminum (TSA) coatings, and aluminum wrapping are most commonly used to reduce the potential for CUI.

8.7.1 Organic coatings

Organic coatings need to be of high quality, immersion grade to provide a barrier to CUI. Some provide good protection for many years. However, poor experience has also been recorded where water ingress into the insulation has caused premature coating breakdown and significant CUI. Organic coatings applied with good quality control procedures are normally considered to have a lifetime of 9–13 years before routine inspection/maintenance is required.

8.7.2 TSA coatings

Historically, TSA coatings have been less commonly applied than organic coatings. TSA coatings have been applied to carbon steel equipment to provide a barrier to CUI. Experience has shown that they perform remarkably well with lifetimes of 20–30³ years before first inspection/maintenance are required, provided that sufficient quality control is applied during surface preparation and coating application. It is important to consider life-cycle costing at the design stage when considering TSA coatings instead of organic coatings.

8.7.3 Insulation coatings

In recent years, insulation coatings have been introduced in situations in which traditional thermal insulation is not required. The insulating property (thermal conductivity) of these water-based acrylic coatings is achieved by adding ceramic beads/spheres or aerogel particles. Because the thermal conductivity is higher than traditional insulation materials and DFTs are limited to approximately 3–5 mm (119–200 mils), the scope of application is limited to personnel protection (PP) or antisweating.

8.7.4 Aluminum wrapping

Aluminum wrapping has most often been applied to insulated austenitic stainless steel equipment and piping to limit the potential for CI-ESCC. Experience has shown that organic coatings do not necessarily provide an effective barrier to CI-ESCC. There is good experience within the industry that aluminum foil wrapping has been a more effective solution than using organic coating because it acts as both a physical barrier and galvanic barrier to preventing CI-ESCC. Care must be taken to ensure that the external insulation weather cladding is correctly applied under the control of appropriate QA levels.

8.8 Insulation system

Poorly designed or applied insulation systems can result in water ingress into the insulation or condensation of water from atmospheric moisture, leading to CUI. The underlying metal also corrodes when insulation becomes wet following the

breakdown of weatherproofing or the vapor barrier after equipment and piping is put into service and is exposed to the weather without a corrective maintenance program. Insulation system life can be prolonged and substrate metal corrosion can be reduced by better design of protrusions, attachments, supports, drainage points, and expansion/contraction joints.

Generally, industrial insulations fall into a number of different categories:

- Cold/cryogenic low temperature,
- Sweating (below ambient) (between 0° and 15–25 °C),
- High temperature (above ambient) applications, and
- Cyclic or dual temperature applications.

For applications that are cold or below ambient temperatures insulation may include polyurethane, polyisocyanurate, flexible elastomeric foams, or cellular glass. These insulation types normally require a vapor barrier under the outer weatherproofing to minimize the potential for condensation of atmospheric moisture.

High temperature insulation typically includes perlite, calcium silicate, mineral wool, and cellular glass. For SHE and local governmental legislation reasons the use of asbestos is no longer specified for new construction.

System movement must be allowed for in the insulation design. Rigid and semi-rigid insulation may require expansion joints and failure to install these can result in uncontrolled movement of the insulation in relation to the equipment or piping. This may result in the vapor barrier or weatherproofing breakdown leading to condensation or ingress of water into the insulation.

Thermal movement caused by, for example, piping expansion or contraction must also be addressed. The linear coefficients of thermal expansion of both the piping and the insulation must be considered. The difference between the amount of pipe and insulation movement, along with routing considerations, normally determines how many expansion/contraction joints are needed in the insulation. Expansion/contraction joints are typically constructed in staggered layers to avoid a path for water ingress.

An insulation system that minimizes water ingress and does not retain water can effectively act as the best barrier to minimize CUI risk. As mentioned before, CUI has been determined under all types of insulation materials. Therefore, the “close cell” insulation materials (e.g., cellular glass) have a lower susceptibility and can provide a more effective barrier to water ingress than “open cell” insulation materials (e.g., mineral wool and calcium silicate) and, therefore, may lower the risk for CUI.

In addition to water absorbency, another factor to consider is the chemical content of the insulation. It should be inert, containing no chemicals that would contribute to corrosion or CI-SCC. Some industrial companies specify a leachable chloride content of less than 10 mg/kg as a way of minimizing the potential for CI-SCC of insulated austenitic stainless steels.

A more recent insulation design is “noncontact insulation.” This design has an air gap between the equipment surface and the insulation. The insulation contacts a mesh screen that is raised above the equipment surface; hence, any ingress of water into the insulation does not contact the equipment to cause corrosion damage. The air gap enables the equipment surface to stay relatively dry and also allows insertion of

a boroscope inspection tool to check the external condition of the equipment without removing the insulation and weatherproofing.

Another insulation design is the aerated system. It is based on an air-cavity between protective cladding-jacketing and insulation material by using a studded foil. This space creates an aerated environment where moisture can evaporate and water can collect at the lowest point.

In addition to these standardized systems, good results are known to occur with the use of drainplugs.

Where there are load bearing supports (e.g., clamp type) it is a good practice to use high-density insulation so that supports can be fitted to the outer weatherproofing so an area for water ingress is not created. Additionally, high-density insulation is recommended at areas of high foot traffic so that if the weatherproofing is walked on it is not easily damaged.

8.9 Weatherproofing

Weatherproofing provides mechanical and weather protection for insulation systems. Although weatherproofing acts as a barrier to CUI, it is susceptible to weather, chemical attack, and foot traffic damage once it is installed. Therefore, it should be adequately maintained.

Insulation weatherproofing materials basically come in two forms, metallic and nonmetallic. The most common metallic weatherproofing materials are aluminized steel, galvanized steel, aluminum, and stainless steel. Common nonmetallic weatherproofing materials are UV-curable, glass-reinforced plastics (GRP), polymeric compounds, coated tapes, and cements.

Metal weatherproofing materials tend to become damaged easily if walked on and this increases the potential for water ingress into the insulation. The use of UV-curable GRP weatherproofing in combination with a higher density insulation material provides a more robust barrier that can support foot traffic without becoming damaged.

The choice of weatherproofing should consider several factors: for example, an assessment of life-cycle costs, the complexity of the equipment/piping, how much foot traffic is expected, the temperature, local maintenance practices, and inspection frequency of the substrate.

The design of weatherproofing needs to take into consideration system movement and thermal expansion/contraction. Metal weatherproofing joints and protrusions are normally sealed with mastic or silicone materials to reduce the potential for water ingress. However, these sealants cannot be relied upon because they weather and break down. It has been proven as much better to overlap joints with swaged edges and fit weatherproof plates around protrusions to minimize the potential for water ingress. The design should be based on practices that minimize the use of sealants.

Weatherproofing should be designed so that it is water repellent and it does not allow water retention. An example of this is using metal weatherproofing that is sloped at column vacuum rings and insulation support rings. Significant experience shows

that using flat weatherproofing at these locations has resulted in water ingress and CUI of the column wall above the vacuum or insulation support ring.

Weatherproofing attachment methods should be compatible with the equipment and piping operating temperatures, particularly where the insulation terminates (e.g., at flanges). Using screws in metal weatherproofing on cold insulation systems may result in puncturing of the protective vapor barrier.

8.10 Implementation

It is important to ensure that the principles highlighted in this chapter are implemented throughout the life cycle of a plant.⁴

For new equipment or plants the user should consider preparing a mechanical design philosophy based on these guidelines that should be implemented during the early stages of the project. Such a design philosophy should address mechanical features that will help to prevent CUI.

The design philosophy should be clear on the use of thermal insulation for personnel protection and should preferably impose the use of protection screens or alternative methods for personnel protection.

It is further important that the user challenge the use of thermal insulation using the guidelines provided in Chapter 4. The user should work closely with the engineering contractor to ensure that materials selection is considered that would help to prevent CUI.

The user should review equipment, piping, and insulation specifications at an early stage to ensure that the same mistakes leading to CUI problems are not repeated. It is also at this stage that critical decisions are made regarding the selection and application of a coating system to protect equipment under insulation. The user should give consideration to the following as a minimum:

- Surface preparation methods and standards
- Application methods
- Shop vs. field application
- The potential for handling damage, and how these should be repaired
- Surface preparation and coating of field welds
- QA/AC; who should be responsible for these, the qualifications of personnel involved, and standards

References

1. CINI Handbook Chapter 4.9.
2. NACE SP0198–2010; Standard Practice; Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A Systems Approach.
3. Fischer, K.P., et.al., “Performance of Thermally-Sprayed Aluminium Coatings in Offshore Service”, Materials Performance, April 1995.
4. Bormuth, K. & de Bruyn, H.J., “Prevention of CUI: Roadmap to Managing CUI”, AIChE Spring Meeting 2011, paper 73a. AIChE 2011.

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Appendix A: Cost: Economic evaluation

Although application of TSA is known to be an effective mitigation strategy for CUI, the initial capital or refurbishment costs tend to be higher than the costs for applying conventional organic coatings. In order to show that it is economically beneficial to apply TSA as an alternative to organic coatings, plant management needs a positive economic evaluation to show that the long-term costs of TSA are actually lower than the costs of conventional organic coatings. The simplest method to show this is to determine the life-cycle costs (LCC) and calculate a discounted cost factor (DCF).

The life-cycle cost determination includes:

- Lifetime cost of acquisition.
- Total erected cost (TEC), namely, the sum of all the direct and indirect costs to install insulation on piping or equipment, including the cost of access (scaffolding), surface preparation, insulation and insulation cladding, coating costs, and installation.
- TEC of any piping that needs replacement.
- Lifetime support cost.
 - The total cost of resources and yearly costs for operation and maintenance.
- Lifetime unavailability cost.
 - The sum of yearly costs due to unavailability of system and loss of earnings.

Life-cycle savings are inherent in the use of TSA and can be very significant. Many large organizations have their own in-house methodologies to determine the LCC and DCF for project evaluations. However, the analysis can be easily performed using a simple spreadsheet. Three examples are given in [Figure A.1-A.3](#).

- a) Small project with an incremental cost of €20k for TSA (€120k vs. €100k). Includes recoating costs. DCF of 21.2% over 30 years.
- b) Project with an incremental cost of €100k for TSA compared to a conventional coating using advanced NDE/NDT after recoating after 12 years. DCF of 26.0% over 30 years.
- c) Project with an incremental cost of €100k for TSA compared to a conventional coating with a CUI incident and recoating costs. DCF of 26.3% over 30 years.

When projected life expectancy or requirement is less than 25–30 years, the cost savings from the use of TSA may not be realized and other coating options may prove optimal from a maintenance budget viewpoint.

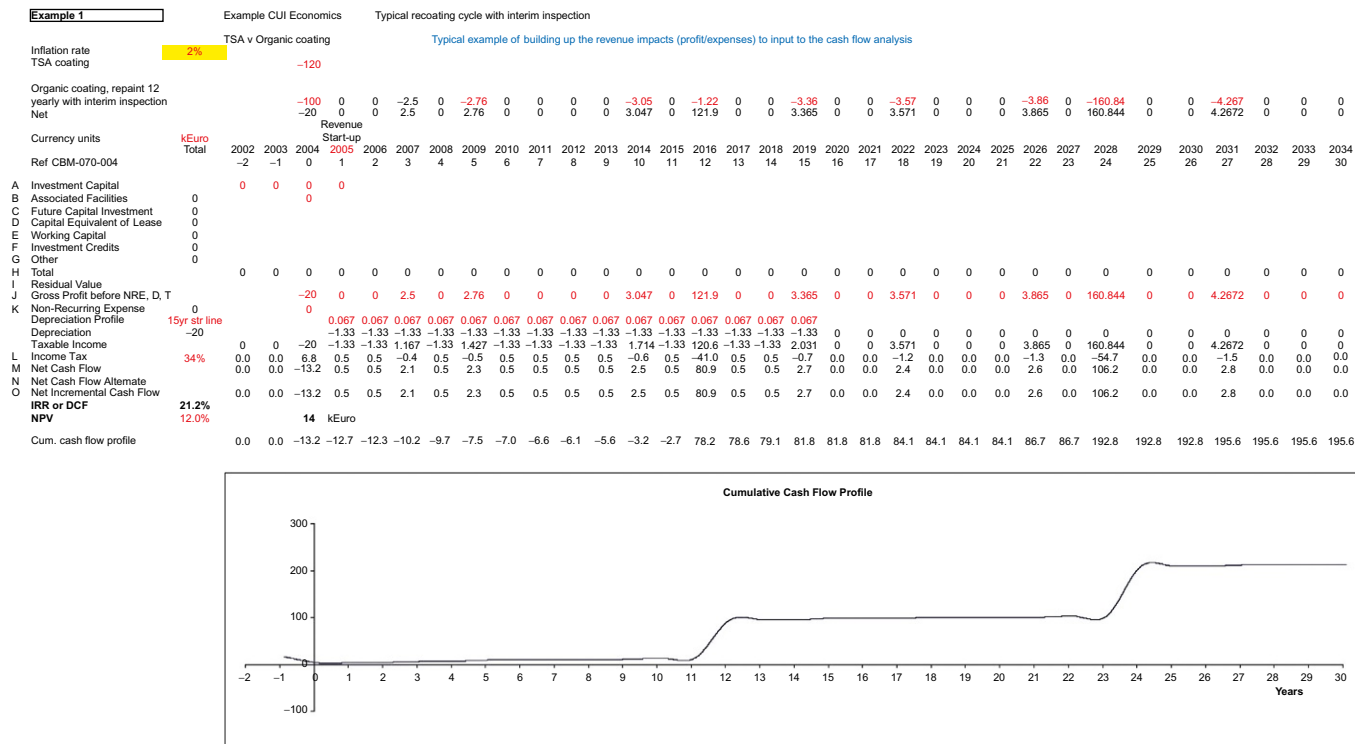


Figure A.1 Example of life cycle cost (LCC). Small project with an incremental cost of €20k for TSA (€120k vs. €100k). Includes recoating costs. DCF of 21.2% over 30 years.

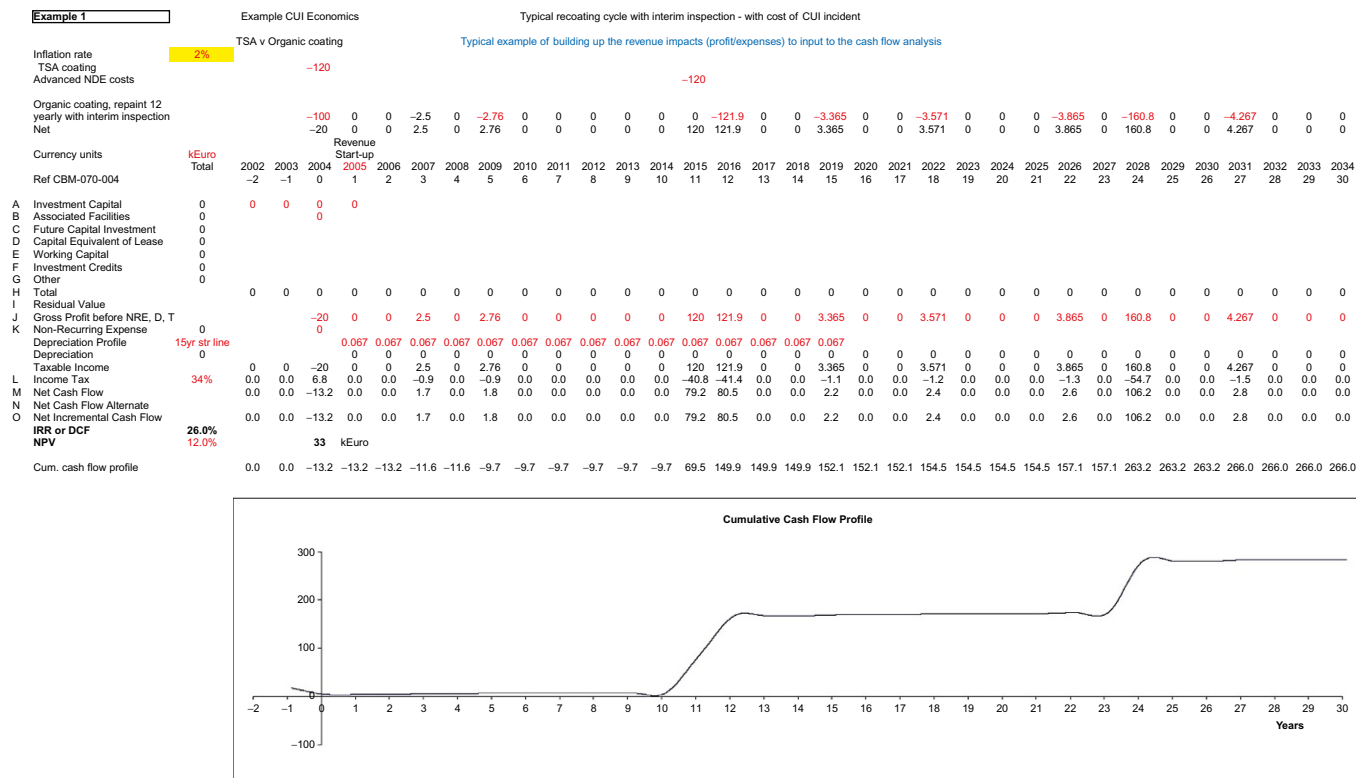


Figure A.2 Example of life cycle cost (LCC). Project with an incremental cost of €100k for TSA compared to a conventional coating using advanced NDE/NDT after recoating after 12 years. DCF of 26.0% over 30 years.

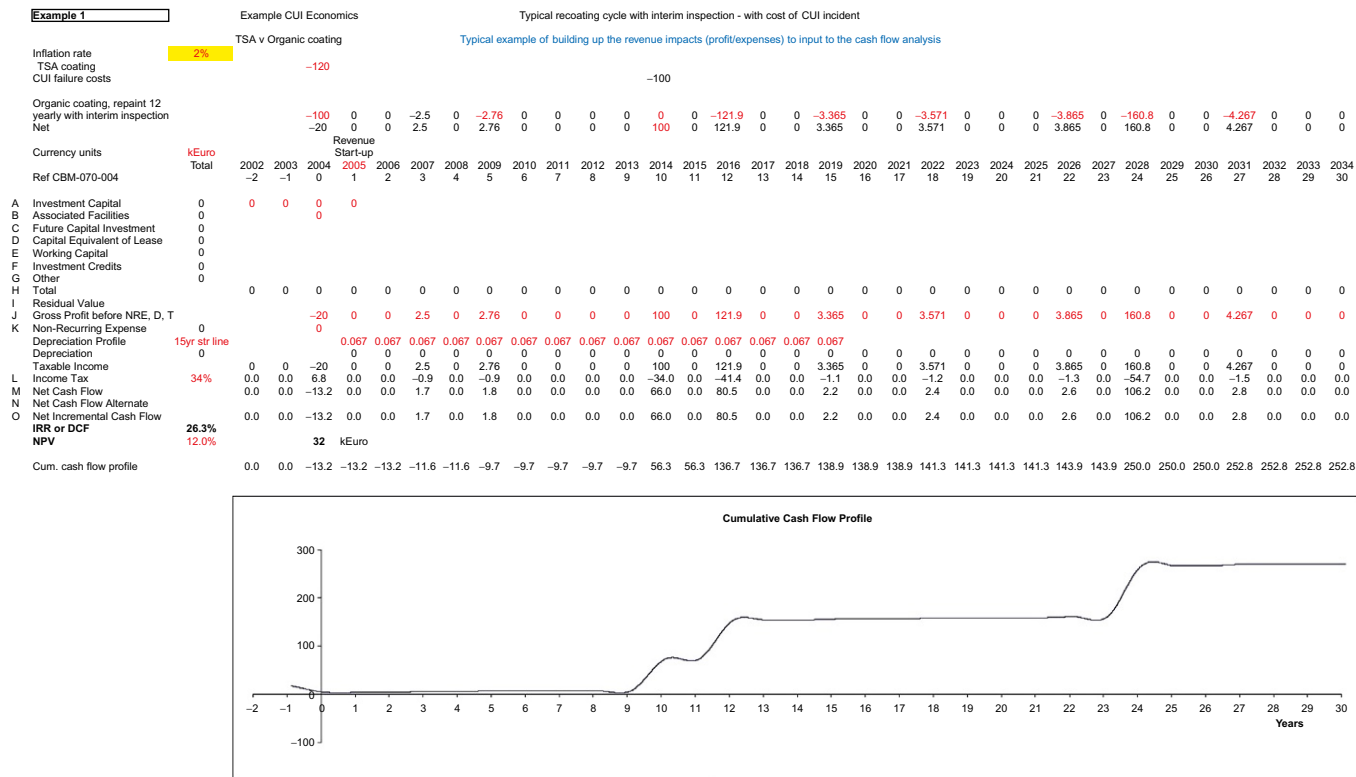


Figure A.3 Example of life cycle cost (LCC). Project with an incremental cost of €100k for TSA compared to a conventional coating with CUI incident and recoating costs. DCF of 26.3% over 30 years.

Appendix B: Quality assurance

- The insulation contractor should present for approval, a quality plan incorporating detailed quality control and testing procedures covering all aspects of the shop fabrication and field installation of insulation systems. The quality plan and quality control procedures shall comply with the requirements of ISO 9001, ISO 9002, or 9003 as appropriate. The insulation contractor may propose incorporation of their own quality control procedures within the quality plan subject to review and ratification by the equipment owner.
- The procedures shall, at a minimum, be based on the quality control agreed to by both, the equipment owner and the insulation contractor and should incorporate inspection verification sheets covering all work stages.
- *Hot insulation:* specific checks that should be undertaken include:
 - Surfaces certified clean and dry and any specified paint system intact when released for insulation.
 - Application details for
 - First insulation layer
 - Second and subsequent layers of insulation (if required)
 - Weather protection sheeting
 - Weather protection including flashings and seals
 - Additional requirements covering
 - Irregular surfaces such as flanges, valves, man-ways, etc.
 - Stainless steel surfaces
 - Hot or acoustic insulation
 - Pre-insulation at a dressing yard or at a fabrication shop (where applicable)
- *Cold insulation:* specific checks that should be undertaken include:
 - Inspection of metal surfaces to be completed prior to insulation; supports, etc., fitted, and hydrotest completed
 - Application details for
 - First insulation layer, no gaps in joints, no cracked or damaged blocks, sealer is fitted, layers are secured to spec
 - Same as above for second layer if fitted
 - Same as above for third layer if fitted
 - Vapor barrier
 - Vapor stops
 - Flange insulation construction
 - Valve box construction
 - Inspection of cladding for sealing, water-shed, support—it should be rejected if sealant not under overlap.
- Insulation installation should be subject to various checks at each stage of the insulation program.
- A pro forma should be used to steward and record each stage of the inspection; the lack of the inspection signature should prevent the next stage of the insulation.
- Due to various different plant conditions, the insulation sections should be broken down into small manageable sections—isometrics and spool pieces or vessel, shell, head, nozzles, etc.

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Appendix C: Additional guidelines on the implementation of CUI best practice

C.1 Maintenance and remediation issues

C.1.1 Roles and responsibilities of maintenance and operations

C.1.1.1 Maintenance

The primary roles and responsibility of maintenance with respect to the prevention of CUI are:

- While repairing insulated equipment, maintenance should ensure that no damage to insulation, insulation seals, or other devices aimed at preventing water ingress occurs.
- If damage does occur, maintenance should carry out repairs to restore the installation to its original condition as quickly as possible.
- When working on insulated equipment, the restoration of the insulation system must be considered an integral part of the job.
- Maintenance should ensure that all work is completed in a timely fashion.
- While carrying out repairs, any other areas of insulation showing distress should be included in the maintenance program.

C.1.1.2 Operations

The primary roles and responsibility of operations with respect to the prevention of CUI are:

- While operating equipment (i.e., operating valves, clearing lines, steaming out systems, washing down spills, walking lines, etc.) measures should be taken to avoid insulation system damage.
- If damage does occur, initiate repairs to restore the installation to its original condition as quickly as possible.
- Ensure that work orders to repair insulation damage in CUI subject areas are addressed appropriately.

C.1.2 Safety considerations

While carrying out maintenance repair work on live equipment, extra safety considerations should be considered. All activities on live equipment should be risk assessed prior to implementation. There are reported instances of failures occurring on the removal of loose scale during initial inspection and even of failures on removal of insulation. It may be necessary to utilize prescreening NDE/NDT to establish that it is safe to remove insulation/scale, etc., and for the surface preparation required for coating.

Although grit blasting on live equipment is a high-risk procedure, it can be carried out after appropriate task risk assessments have been carried out.

C.1.3 SHE concerns with asbestos and lead paint removal

Regulations are in force to prevent exposure of employees to asbestos and lead. If this is not reasonably practicable, the law says their exposure should be controlled to the lowest possible level. Before any work with asbestos or lead paint is carried out, the regulations require employers to make an assessment of the likely exposure of employees to asbestos and lead dust. The assessment should include a description of the precautions to be taken to control dust release and to protect workers and others who may be affected by that work. Companies employing a contractor to work on their premises must make sure that either the work will not lead to asbestos or lead exposures or that the contractor has carried out this assessment and identified work practices to reduce exposures.

C.2 Minimum standards

Need to identify the criteria for a minimum standard

- NACE RP0198-2004: The control of corrosion under thermal insulation and fireproofing materials—a systems approach.

C.3 Types of insulation service

C.3.1 Equipment in cyclic service

Equipment normally operated outside the CUI temperature range but in cyclic service other than start-up/shutdown should also be included in the CUI program. The corrosion rate during cyclic heat-up will be an order of magnitude higher than under non-cyclic conditions. Therefore, it is not recommended to take any credit for the period that the equipment is operating outside of the CUI temperature range, unless the cyclic frequency is very low (e.g., once every 3–4 months or lesser).

C.3.2 Equipment in sweating service

Equipment in sweating conditions requires site-specific considerations. Vapor barriers cannot be guaranteed to prevent the air from entering the insulation. Therefore, one should assume that insulation on equipment that operates regularly or permanently below ambient temperature is "wet" unless proven differently. Sweating conditions may also exist locally; for example, in piping downstream of letdown valves, where the expansion/evaporation of the product leads to a cool-down of the product. If the initial operating temperature is sufficiently close to ambient temperature, this cool-down can result in cold spots below ambient resulting in water condensation under an even perfect insulation.

C.3.3 Equipment adjacent to cooling towers

Equipment which is situated close to cooling towers, especially if austenitic stainless steels are being used as materials of construction, requires specific consideration. The cooling tower drift from the exhaust plume will typically be laden with a high concentration of chlorides which can be deposited onto the equipment under certain weather conditions. Vapor barriers cannot be guaranteed to prevent the air from entering the insulation, condensing, and depositing chloride residues. Both carbon manganese and low alloy steel and austenitic stainless steel piping and equipment require the use of high integrity coatings. TSA is recommended for carbon manganese and low alloy steel to prevent CUI and aluminum foil wrap for austenitic stainless steel to prevent ESCC.

C.3.4 Equipment close to freezing point

For carbon and low alloy steel equipment operating just below the freezing point (e.g., using liquid propane at atmospheric pressure), if the insulation is in good condition, it can be assumed that any water in contact with the surface will be frozen, so CUI is unlikely. This assumption is not true for the vapor phase.

C.3.5 Deluge systems

Deluge systems are not typical for insulated equipment. Nevertheless, it can happen that only some parts, an instrument or a small bore piping tie-in, are insulated. Also possible is that the deluge system was not properly designed and installed, and can spray its water over adjacent insulated equipment. It is important to pay attention during visual inspection to the presence of any deluge system on or near the insulated equipment.

C.3.6 Steam tracing

Steam tracing leaks will cause greatly accelerated CUI rates and therefore steam tracing is not recommended. It is important to keep the steam tracing in good condition and not leaking. A leaking steam tracing system is clearly a location for increased CUI rates and should, therefore, be part of a routine inspection procedure. Use of copper tubing will reduce the probability of steam tracing leaking, however, in the case of wet insulation, copper or any other CRA (corrosion-resistant alloy) may increase the CUI corrosion rate (galvanic effect) at the higher operating temperature.

C.4 Surface preparation

C.4.1 Overview

Coating systems suitable for long-term protection against CUI must be resistant to hot water immersion. The environment beneath insulation can be very severe. As with

new construction, surface preparation and steel cleanliness are crucial in maximizing the performance life of any coating system. No suitable alternatives to abrasive blasting have been found to compare favorably as it relates to performance life and/or economics. In spite of this, there is a general reluctance to perform the necessary "grit" blasting in in-situ maintenance situations like CUI.

C.4.2 Scaffolding

Scaffolding is expensive, but access for inspection, surface preparation and coating application is required. The most efficient way to minimize scaffolding is to eliminate its need through intelligent selection of inspection areas. When the inspection strategy calls for sampling of certain types of locations or configurations, select those that are close to grade, near platforms, ladders, or walkways. When this cannot be done, inspectors should select those that are accessible by rolling ladder or other means. For the remaining points, rope access may prove to be the most cost effective, quickest, and safest alternative to traditional scaffolding or mobile crane access.

C.4.3 Surface preparation

Depending on the surface condition, accessibility, and local circumstances, the following surface preparation methods are available (Table C.1).

- *ISO-St2—Deep manual or mechanical cleaning:* The surface must be free of oil, grease, and dirt to the naked eye and without badly adhered calamines or dust or remains of paint or extraneous materials.
- *ISO-St3—Very deep manual or mechanical cleaning:* The same as for St2, but the surface is treated much deeper to obtain the metallic shine which is characteristic of a metal underlayer.
- *ISO-Sa—Blasting:* Before blasting, any thick layers of rust must be removed with scrapers. Oil, grease, and visible dirt must also be removed.
- *ISO-Sa1—Light blasting:* The surface must be free of oil, grease, and dirt to the naked eye and without badly adhered calamines or dust or remains of paint or extraneous materials.
- *ISO-Sa2—Deep blasting:* The surface must be free of oil, grease, and dirt to the naked eye and without most calamines or dust or remains of paint or extraneous materials. Any residual contamination must be firmly adhered.

Table C.1 Surface preparation standards

Manual derusting	St-3	(in accordance with ISO 8501-2:1994)
Power tool cleaning	St2–3	(in accordance with ISO 8501-2:1994)
Wet blasting	Sa-2½	(in accordance with ISO 8501-2:1994)
Hydro jetting	Sa-2½	(in accordance with ISO 8501-2:1994)
Dry blasting	Sa-2½	(in accordance with ISO 8501-2:1994)

- *ISO-Sa2½—Very deep blasting*: The surface must be free of oil, grease, and dirt to the naked eye and without calamines or dust or remains of paint or extraneous materials. The only traces of contamination admissible are insignificant stains in spots or on sides.
- *ISO-Sa3—Blasting until the steel is visibly clean*: The surface must be free of oil, grease, and dirt to the naked eye and without calamines or dust or remains of paint or extraneous materials. It must have a uniform metal color.

C.4.4 Grit blasting

Most abrasive blast media can be classified into one of four general types (Tables C.2 and C.3).

- Natural minerals (e.g., silica sand, garnet, olivine)
- Manufactured media (e.g., steel shot, glass grit, alumina, plastic pellets or beads, solid carbon dioxide, sodium bicarbonate)
- Mineral slag (e.g., copper slag, nickel slag, and coal slag)
- Organic media (e.g., corn cobs, nut shells, starch grains)

C.4.5 Wet abrasion (jet cleaning)

Water washing at very high pressure

- *Pressure*: More than 2000 barg
- *Cleaning speed*: maximum 10–12 m/h depending on the material to be eliminated
- *Use*: Complete elimination of coatings and rust. The result is comparable to that of dry abrasive blasting but with premature oxidization after drying.

C.4.6 Water washing at pressure

- *Pressure*: up to 1300 barg
- *Cleaning speed*: maximum 5 m/h depending on the material to be eliminated. This method, at much lower pressure, is used to eliminate contamination from any layer underneath
- *Use*: Elimination of salts and other contaminants, coatings, and rust

C.4.7 Wet abrasive blasting at low pressure

- *Pressure*: 6–8 barg
- *Cleaning speed*: maximum 10–16 m/h, depending on the material to be eliminated
- *Use*: Reduces abrasion, dust, eliminates salts, avoids danger of sparking. The result is comparable to that of dry abrasive blasting but with premature oxidation after drying

C.4.8 Steam cleaning

- *Pressure*: 100–120 barg
- *Use*: Eliminates soluble contamination in water or water emulsions: the layer under dries quicker than with scouring with water

Table C.2 Summary of abrasive characteristics¹

Abrasive	Composition	Mohs hardness	Density (g/cm ³)	Dusting	Recycling
<i>Silica sand</i>					
Best quality	Crystalline silica	7.0	1.6	Low	No
Average quality	Crystalline silica	6.5	1.6	High	No
Staurolite/zircon	Iron aluminum silicate	7.5	2.0	Mod	No
<i>Garnet</i>					
Almandite	Iron aluminum silicate	7.5	2.0	Low	Yes
Andradite	Calcium silicate	6.5	1.8	High	No
Olivine	Iron silicate	6.5	1.9	High	No
Spec. Hematite	Iron oxide	6.0	2.3	Mod	Yes
Copper slag	Iron silicate glass	6.0	1.6	Mod	No
Nickel slag	Nickel iron glass	6.0	1.6	High	No
Iron slag	Iron silicate glass	6.0	1.6	High	No
Coal boiler slag	Ca, iron silicate glass	6.0	1.4	High	No
Steel grit/shot	Iron (steel)	6.0	2.2+	Low	Yes
Baking soda	Sodium carbonates	2–3	1.1	High/low ^a	No
Crushed glass	Alkaline silicate glass	6.0	1.6	High	No
Organic media	Various	2–3	0.6–1.0	N/A	No

^a High dusting when used dry; low dusting when used with water.

¹ J.D. Itansink, 'An introduction to abrasives for protective coating removal operations', J. Prot. Coatings Linings, 2000, 17(4), 66–73.

Table C.3 Physical properties and comparative characteristics of nonmetallic abrasives

Description	Glass beads ^a	Coarse mineral abrasives ^b	Fine angular mineral abrasives ^c	Organic soft grit abrasives ^d	Plastic abrasives ^e
Physical properties					
Shape	Spherical	Granular	Angular	Irregular	Cylindrical (diameter/length = 1)
Color	Clear	Tan	Brown/white	Brown/tan	Nylon: white, polycarbonate: orange
Specific gravity	2.45–2.50	2.4–2.7	2.4–4.0	1.3–1.4	Nylon: 1.15–1.17, polycarbonate: 1.2–1.65
Free silica content	None	100%	<1%	None	None
Free iron content	<1%	<1%	<1%	None	None
Hardness (MOH)	5.5	7.5	9.0	1.0	R110–R120
Media comparisons					
Toxicity	None	High	Low	Low/none	None
Metal removal	Low/none	High	High	None	Deburring only
Cleaning speed	Medium/high	High	High	Low	Low
Peening ability	High	None	None	None	None
Finish achieved	Range (various matte)	Rough anchor	Various matte	Smooth	Smooth
Surface contamination	None	Medium	Medium	Medium/high	Low to none
Suitability for wet blasting	High	Low	Low	Low	Low
Suitability for dry blasting	High	High	High	High	High
Standard size ranges	20–325	8–200	80–235	60–325	0.76 by 0.76 mm (0.030 by 0.030 in.)

Continued

Table C.3 Continued

Description	Glass beads ^a	Coarse mineral abrasives ^b	Fine angular mineral abrasives ^c	Organic soft grit abrasives ^d	Plastic abrasives ^e
	U.S. mesh	U.S. mesh	U.S. mesh	U.S. mesh	1.1 by 1.1 mm (0.045 by 0.045 in.) 1.5 by 1.5 mm (0.060 by 0.060 in.)
Consumption rate	Low	High	Medium	High	Very low
Cost comparison	Medium	Low	High/medium	High/medium	High/medium

^a Glass beads are used for cleaning, finishing, light-to-medium peening, and deburring.
^b Coarse mineral abrasives such as sand are used where metal removal and surface contamination are not considered.
^c Fine angular mineral abrasives such as aluminum oxide are used in cleaning when smooth finish and surface contamination are not important.
^d Organic soft grit abrasives, for example, walnut shells, are used in light deburring and cleaning of fragile items.
^e Plastic abrasives such as nylon and polycarbonate are used to deflash thermoset plastic parts and deburr finished machine parts.
Source: ASM metals handbook, 9th edition, vol. 5 1982; Pera 2003.

C.4.9 Vacuum blasting

Vacuum blasting quickly removes surface coatings leaving an abraded substrate, while generating minimal waste and virtually no dust emissions.

The technology offers a safe, economical, and efficient means for cleaning up hazardous materials from different types of surfaces. Benefits include:

- Increased productivity for cleanup of contaminated facilities by more than 50% over baseline
- Minimal waste generation (1% of conventional open blasting) and virtually no dust emissions
- Minimized worker exposure to hazardous contaminants
- Improved ergonomics from lightweight construction of the blast head

Although the productivity of vacuum blasting is lower than for conventional blasting, which increases the cost, the total cost of vacuum blasting may be similar due to lower scaffolding and sheeting requirements.

C.4.10 Mechanical surface preparation

The cost associated with dust containment and debris disposal may be significant but the improvement in coating integrity and, therefore, life means that blasting should always be applied wherever possible. When blasting cannot be successfully applied it will be necessary to use power tools or manual preparation techniques. It should be recognized that in these cases the coating life will be substantially shortened and re-inspection schedules should be set accordingly. These methods are not recommended but sometimes are unavoidable.

C.4.10.1 Mechanical brushing

Mechanical brushing is usually done with rotating wire brushes. The main disadvantage is that the surfaces treated are not usually corrosion free and are often polished and contaminated with oil. This makes the adhesion of any coating less effective and impairs the system's performance.

C.4.10.2 Descaling

Mechanical descaling is usually done in combination with mechanical brushing. It is appropriate for small repairs and can be used to eliminate thick coats of rust and to cheapen subsequent blasting operations.

C.4.10.3 Pin hammer

To eliminate rust, paint, etc., from corners and angles and obtain a clean surface with a profile.

C.4.10.4 Sanding with grinding discs

Sanding with a grinding disc requires the use of one or more rotating discs covered with an abrasive material. The system is used for small repairs or for eliminating particles/notches.

C.4.11 *Nondust (vacuum) grit blast technology*

Alternative grit blast such as the following should be considered in order to reduce dust contamination. Dust control is simplified (no boxing in structures) and the risk of eye injuries is reduced.

C.4.11.1 *Sponge jet*

Sponge jet is a composite of urethane sponge and a cleaning (or abrasive) agent. This patented technology utilizes the pliable, open-celled characteristics of urethane sponge and the cleaning and cutting power of a cleaning agent or conventional abrasive. The pliant nature of the sponge media allows it to flatten on impact, exposing the cleaning agent or abrasive. After leaving the surface, it then constricts, entrapping most of what would normally have become airborne contaminants. Blasted media is collected and processed through either electric or pneumatic classifiers, which separate the sponge media abrasives into three categories: oversized debris, reusable media, and fines (consisting of spent media and dust). Up to 94% of sponge media abrasives are reusable after each blast cycle.

C.4.11.2 *Solid carbon dioxide (CO₂)*

There are four cleaning methods using carbon dioxide:

- Macroscopic hard and dense dry ice pellets
- Softer microscopic “snow” particles
- Liquid CO₂ washing systems
- Supercritical fluid carbon dioxide (SFCO₂)

Whichever process is used, cleaning depends on the liquid carbon dioxide solvent properties, the energy and momentum transfer by the impacting solid phase, or a combination of solvent properties and momentum or energy transfer. Pellet systems rely upon the thermomechanical impact stresses related to the high impact velocity of macroscopic pellets for contamination removal—a momentum and energy transfer process. Snow sprays rely upon a combination of the solvent action of liquid CO₂ and the momentum transfer of high velocity microscopic snow particles. The liquid based CO₂ washing systems rely on the liquid phase solvent properties. Finally, the SFCO₂ systems rely exclusively upon carbon dioxide’s unique supercritical fluid properties.

Appendix D: Coatings

D.1 Introduction

Protective coatings include thermal or flame sprayed metallic systems as well as the traditional organic and inorganic coating systems. Each of these systems has their place in the prevention of CUI. Coating system selection and application is of great importance in mitigation and prevention of CUI as recognized by the NACE SP0198 2010 document “The Control of Corrosion under Thermal Insulation and Fireproofing Materials—A Systems Approach.”

Protective coatings have been recognized and accepted and are recommended as a highly effective method of protecting insulated metallic substrates such as these steels from corrosion. Attempts to prevent water from entering insulated systems have not been successful, and corrosion protection techniques such as inhibitors and cathodic protection have been less effective than protective coatings in mitigating CUI.

Some coating systems may be more effective than others but may cost more. An economic, life-cycle analysis can be very effective in determining which system to apply in a particular situation. This document will not include a detailed discussion of the various types of coatings that are available, which can be used to protect piping and vessels, which will be insulated. The reader is encouraged to consult the NACE RP0190-2004 guideline “The Control of Corrosion under Thermal Insulation and Fireproofing Materials—A Systems Approach” for guidance. This document contains a very detailed section on protective coatings.

D.2 Protective coatings and protective coating selection

This section details information for the selection of protective coatings for carbon manganese and low alloy steel and austenitic stainless steels under thermal and/or noise reduction insulation systems. There are several factors that are important in proper coating system selection. Specifications should identify the maximum temperature that the insulated vessel, pipeline, or equipment may experience during normal operation and maintenance preparation to ensure that the coating system is selected accordingly. The following critical questions can be used as guidance:

- Have the normal operating temperature, possible upset temperature, and start-up/shut down temperature been correctly considered?
- Will there be thermal cycling as part of the process?

Each coating solution will have its own specific advantages and disadvantages. These could relate to lifetime cost and ease of application.

An economic, life-cycle analysis may be very effective in determining which system to apply in a particular situation. As in most cases, no one system is probably appropriate for all situations such as new construction, touch up after erection, maintenance, application during outages, application while the operation continues, and surface preparation options. The reader/owner/specification engineer needs to determine the best way forward for the facility and its components.

Proper application of the selected coating system will allow the coating to perform as designed. Attention to detail and rigorous third party inspection with hold points can help to achieve superior CUI coating life. Surface preparation is a major component of a protective coating system. Issues related to inaccessibility of areas for surface preparation and coating application can provide for less than expected performance of coatings. Of course, coating systems for new construction must all be touched up after erection and throughout the life of the equipment. Some older coating systems have shown less than desirable service and this may be a result of not understanding the actual thermal service and other electrolytic corrosion conditions that can develop in these insulated environments; or, premature failure may be related to poor surface preparation and coating application.

Most owners familiar with elevated temperature coatings agree that with a properly trained and equipped staff, both TSA and liquid-applied coatings can be applied correctly and can provide for a long service life. The expectation is that TSA coatings as well as inorganic and organic coatings will provide for years of corrosion protection when properly selected and applied. However, there are many cases where the wrong coating has been selected for the job, and also many cases where the correct coatings were chosen but applied incorrectly. Both scenarios can lead to premature failure of coatings to provide the corrosion protection and service life expected. This applies to both TSA and liquid-applied coatings.

D.3 Thermal spray aluminum

A comparison between thermally sprayed aluminum and conventional paint systems for the protection of steel under insulation is provided in Table 7.1.

D.4 Excerpt from NACE SP0198-2010 Section 4 protective coatings

Section 4: Protective coatings

4.1 Scope

4.1.1 This section presents information for the selection of protective coatings for carbon steel and austenitic and duplex stainless steels under thermal and/or noise reduction insulation systems and fireproofing. Protective coatings have been recognized and accepted and should be

used as a highly effective method of protecting insulated carbon steel and austenitic and duplex stainless steel from corrosion. Attempts to prevent water from entering insulated systems are not sufficiently reliable to prevent CUI, and corrosion protection techniques such as inhibitors and cathodic protection have been less effective than protective coatings in mitigating corrosion under insulation.

4.1.2 Coating systems considered in this section are thin-film liquid-applied coatings, fusion-bonded coatings, metalizing (thermal spray), and wax-tape coatings. These systems have a history of successful use. Other systems may also be satisfactory.

4.1.3 Insulation covering (lagging) is not addressed in this section. See Section 5.

4.1.4 Coating manufacturers or project specifications should be consulted regarding the suitability of specific products for carbon steels, austenitic stainless steels, and duplex stainless steels under insulation systems. Potentially deleterious interactions with leachable material from the insulation may affect the coating systems.

4.2 Coating austenitic and duplex stainless steels under thermal insulation

4.2.1 Austenitic and duplex stainless steels can be subject to ESCC when covered with insulation. Also, if a metal-containing coating is heated beyond the metal's melting point, liquid metal cracking (LMC) of austenitic and duplex stainless steels may occur. Consequently, the criteria for a coating system used to prevent ESCC and LMC of austenitic and duplex stainless steels are as follows:

4.2.1.1 The coating system shall not contain free, soluble chlorides or other halides after curing beyond those levels established by ASTM C795 and ASTM C871. Chlorides are present in normal environments and, over time, usually exceed the amount contributed by coating systems. Compounds of chlorides or other halides within the cured-resin chemical molecule are not considered harmful unless they are subject to release through aging within the expected service temperature range.

4.2.1.2 Because of the potential for LMC, the coating shall not contain metallic zinc in its formulation.

4.2.1.3 The coating shall be selected for the expected service temperature range if this range could allow moisture to occur on substrate surfaces. This is especially true with processes using intermittent thermal cycling through the dew point.

4.2.2 Table 1 lists typical protective coating systems for austenitic and duplex stainless steel equipment. Maximum and minimum service temperatures and their duration in the proposed application should be considered in selecting a coating system. For other coating systems, the manufacturer should be consulted regarding expected coating system performance.

4.2.3 Aluminum foil wrapping may be used to prevent ESCC of austenitic and duplex stainless steels under insulation.

4.3 Coating carbon steel under thermal insulation and fireproofing

4.3.1 The coating systems recommended for use on carbon steel operating below 175°C (350°F) under thermal insulation are typically tank lining systems formulated to prevent corrosion. Other coatings may be used at the buyer's discretion.

4.3.2 Epoxy protective coatings, as a class of materials, should be used on carbon steel under fireproofing.

4.3.3 If galvanized steel under fireproofing has been corroding, coating the galvanized steel should be considered. The manufacturer of proprietary fireproofing should be consulted regarding the compatibility of the fireproofing with galvanized steel.

4.3.4 Users who purge piping with steam shall select a coating system capable of withstanding the surface temperature for the duration of the purging. The coating manufacturer should be consulted for specific temperature resistance information.

4.3.5 Inorganic zinc-rich coating shall not be used by itself under thermal insulation in the 50–175°C (120–350°F) service temperature range for long-term or cyclic service. Zinc provides

inadequate corrosion resistance in closed, sometimes wet, environments. At elevated temperatures greater than approximately 60 °C, the zinc may undergo a galvanic reversal whereby the zinc becomes cathodic to the carbon steel.

4.3.6 Thermal-sprayed aluminum (TSA) coatings have performed successfully in marine and high-temperature environments.

4.3.7 Wax-tape coatings may be used to prevent corrosion of carbon steel during a dry cycle or when cycling through the dew point. Tape application procedures should follow those prescribed in NACE Standard RP037513 for wax-tape coating systems.

4.3.8 Table 2 lists protective coating systems typically used for carbon steel equipment. The user should select the coating system appropriate for the expected temperature range. Maximum and minimum service temperatures and their duration in the proposed application should be considered in selecting a coating system. For other coating systems, the manufacturer should be consulted regarding expected coating system performance.

The following is a combination of Tables 1 and 2 from NACE SP0198-10. See [Tables D.1–D.3](#). A few rows were deleted, as these are not recommended systems. Likewise both stainless- and carbon steels were combined to reduce the repetition of the information provided.

Table D.1 Typical protective coating systems for austenitic and duplex stainless steels under thermal insulation

System number	Temperature range ^{a,b}	Surface preparation ^c	Surface profile, μm (mil) ^d	Prime coat, μm (mil) ^e	Finish Coat, μm (mil) ^e
SS-1	−45 to 60 °C (−50 to 140 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	High-build epoxy, 125–175 (5–7)	N/A
SS-2	−45 to 150 °C (−50 to 300 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
SS-3	−45 to 205 °C (−50 to 400 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy novolac, 100–200 (4–8)	Epoxy novolac, 100–200 (4–8)
SS-4	−45 to 540 °C (−50 to 1000 °F)	SSPC-SP 1 and abrasive blast	15–25 (0.5–1.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)
SS-5	−45 to 650 °C (−50 to ~1200 °F)	SSPC-SP 1 and abrasive blast	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, ^f 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix, ^f 100–150 (4–6)
SS-6	−45 to 595 °C (−50 to 1100 °F)	SSPC-SP 1 and abrasive blast			

^a The temperature range shown for a coating system is that range over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of austenitic and duplex stainless steels at certain temperatures. Temperature ranges are typical for the coating system; however, specifications and coating manufacturer's recommendations should be followed. SS-4, SS-5, SS-6, and SS-7 may be used under frequent thermal cyclic conditions in accordance with manufacturer's recommendations.

^b Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures. An experienced metallurgist should be consulted before exposing duplex stainless steel to temperatures greater than 300 °C (572 °F).

^c To avoid surface contamination, austenitic and duplex stainless steels shall be blasted with nonmetallic grit such as silicon carbide, garnet, or virgin aluminum oxide. Because there are no specifications for the degree of cleanliness of abrasive blasted austenitic and duplex stainless steels, the owner should state the degree of cleanliness required after abrasive blasting, if applicable, and whether existing coatings are to be totally removed or whether tightly adhering coatings are acceptable.

^d Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. Coating manufacturer's recommendations should be followed.

^e Coating thicknesses are typical dry film thickness (DFT) values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

^f Consult with the coating manufacturer for actual temperature limits of these coatings.

Table D.2 Combined protective coating systems for carbon steels under thermal insulation

System number	Temperature range ^{a,b}	Surface preparation	Surface profile (μm) ^c	Prime coat (μm) ^d	Finish coat (μm) ^d
C-S-1	−45 to 60 °C	ISO SA-2.5	50–75	High-build epoxy, 130	Epoxy, 130
C/S-2 (shop application only)	−45 to 60 °C	ISO SA-2.5	50–75	N/A	Fusion-bonded epoxy (FBE), 300
C/S-3	−45 to 150 °C	ISO SA-2.5	50–75	Epoxy phenolic, 100–150	Epoxy phenolic, 100–150
C/S-4	−45 to 20 °C	ISO SA-2.5	50–75	Epoxy novolac or silicone hybrid, 100–200	Epoxy novolac or silicone hybrid, 100–200
C/S-5	−45 to 595 °C	IISO SA-3	50–100	TSA, 250–375 with minimum of 99% aluminum	Optional: Sealer with either a thinned epoxy or silicone coating (depending on service temperature) at approximately 40 thickness
C/S-6	−45 to 650 °C	ISO SA-2.5	40–65	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150
S-7	−45 to 540 °C	N/A	N/A	Aluminum foil wrap with min. thickness of 64 (2.5)	N/A

C-8 ^c Bulk or shop-primed pipe, coated with inorganic zinc	−45 to 400 °C	Low-pressure water cleaning to 20 MPa if necessary	N/A	N/A	Epoxy novolac, epoxy phenolic, silicone, modified silicone, inorganic copolymer, or a coating with an inert multipolymeric matrix is typically applied in the field. Consult coating specialist, manufacturer for thickness and service temperature limits ^f
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C, carbon steel; S, stainless steel.

^a The temperature range shown for a coating system (including thermal cycling within this range) is that range over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of carbon steel at certain temperatures. Temperature ranges are typical for the coating system; however, not all coatings in a category are rated for the given minimum/maximum temperature. Specifications and coating manufacturer's recommendations should be followed for a particular coating system.

^b Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures.

^c Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. The coating manufacturer's recommendations should be followed.

^d Coating thicknesses are typical DFT values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

^e If inorganic zinc-rich coating is applied in a shop and topcoat is applied in the field, proper cleaning of the inorganic zinc-rich coating is required. The use of inorganic zinc-rich coating under insulation is not a preferred system for service temperatures in the CUI range up to approximately 175°C (350°F). However, bulk piping is often coated with inorganic zinc-rich coating in the shop and some owners purchase this piping for use under insulation. In these cases, the inorganic zinc-rich coating should be topcoated to extend its life.

^f Consult with the coating manufacturer for actual temperature limits of these coatings.

Table D.3 Typical protective coating systems for carbon steels under thermal insulation and fireproofing

System number	Temperature range ^{a,b}	Surface preparation	Surface profile [μm (mil)] ^c	Prime coat [μm (mil)] ^d	Finish coat [μm (mil)] ^d
CS-1	−45 to 60 °C (−50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	High-build epoxy, 130 (5)	Epoxy, 130 (5)
CS-2 (shop application only)	−45 to 60 °C (−50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	N/A	Fusion-bonded epoxy (FBE), 300 (12)
CS-3	−45 to 150 °C (−50 to 300 °F)	NACE No. 2/SSPC- SP 10	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
CS-4	−45 to 205 °C (−50 to 400 °F)	NACE No. 2/SSPC- SP 10	50–75 (2–3)	Epoxy novolac or silicone hybrid, 100–200 (4–8)	Epoxy novolac or silicone hybrid, 100–200 (4–8)
CS-5	−45 to 595 °C (−50 to 1100 °F)	NACE No. 1/ SSPC-SP 5	50–100 (2–4)	TSA, 250–375 (10–15) with minimum 99% aluminum	Optional: Sealer with either a thinned epoxy-based or silicone coating (depending on maximum service temperature) at approximately 40 (1.5) thickness
CS-6	−45 to 650 °C (−50 to 1200 °F)	NACE No. 2/SSPC-SP 10	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)
CS-7	60 °C (140 °F) maximum	SSPC-SP 2 or SSPC-SP 3	N/A	Thin film of petrolatum or petroleum wax primer	Petrolatum or petroleum wax tape, 1–2 (40–80)

CS-8 Bulk or shop-primed pipe, coated with inorganic zinc	–45 to 400 °C (–50 to 750 °F)	Low-pressure water cleaning to 3000 psi (20 MPa) if necessary	N/A	N/A	Epoxy novolac, epoxy phenolic, silicone, modified silicone, inorganic copolymer, or a coating with an inert multipolymeric matrix, is typically applied in the field. Consult coating manufacturer for thickness and service temperature limits ^e
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^a The temperature range shown for a coating system (including thermal cycling within this range) is that range over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of carbon steel at certain temperatures. Temperature ranges are typical for the coating system; however, not all coatings in a category are rated for the given minimum/maximum temperature. Specifications and coating manufacturer's recommendations should be followed for a particular coating system.

^b Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures.

^c Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. The coating manufacturer's recommendations should be followed.

^d Coating thicknesses are typical DFT values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

^e If inorganic zinc-rich coating is applied in a shop and topcoat is applied in the field, proper cleaning of the inorganic zinc-rich coating is required. The use of inorganic zinc-rich coating under insulation is not a preferred system for service temperatures in the CUI range up to approximately 175 °C (350 °F). However, bulk piping is often coated with inorganic zinc-rich coating in the shop and some owners purchase this piping for use under insulation. In these cases, the inorganic zinc-rich coating should be topcoated to extend its life.

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Appendix E: Application of thermal sprayed aluminum

E.1 Thermal spray application

Thermal spray coatings are applied by a process in which a metal powder, an organic powder, or metal wire is melted and the spray deposited onto a surface. Historically, metallizing was the term used to describe wire flame spraying. However, due to dramatic improvements in the equipment used to heat and spray the molten metal and non-metallic polymers onto a surface, the term thermal spraying is more descriptive. Thermal spraying is a process by which a finely divided molten metallic or non-metallic material is sprayed onto a prepared substrate to form a coating. The sprayed material is originally in the form of a wire or powder—wire is the preferred feedstock for TSA. The thermal spray gun heats the wire to a molten state and compressed gas propels it to the surface being covered, depositing it as a coating.

Zinc, aluminum, and their alloys are the metals most widely used for thermal spray, corrosion-resistant protection coatings. These metals provide excellent corrosion protection in a variety of marine and industrial environments. In general, aluminum corrodes less rapidly than zinc in highly acidic conditions, but zinc performs better in alkaline environments. Aluminum is the preferred material due to possible SHE concerns (related to dust production during thermal spraying) with the use of zinc alloys in confined environments; hence, the generic term for thermal sprayed aluminum is “TSA.” After spray application, the coatings are anodic to the underlying steel surface. When corroded, the oxidized aluminum coating functions primarily as a barrier coating.

One advantage of the thermal spray application system is that essentially no start-up or clean-up procedures are involved. The wire feedstock is fed to the spray gun, the heat source is ignited, and spraying of the molten feedstock begins. On conclusion of thermal spraying, the device is shut off and the process stops, with virtually no equipment clean-up being required.

The particles bond to the substrate mechanically. Particle velocity, substrate roughness, particle size, material chemistry, particle temperature, and substrate temperature influence the bond strength of the coating material. The process was originally referred to as flame spraying, metal spraying, flame plating or metallizing, when it was limited to the oxygen-fuel (oxy-fuel) wire spray method.

Currently seven major commercially available thermal spray processes are in use. We are typically only interested in the first two.

- Oxy-fuel wire (OFW) spray
- Twin wire electric arc (TWEA) spray

- Oxy-fuel powder (OFP) spray
- Plasma arc (PA) powder spray
- High velocity oxy-fuel (HVOF) powder spray
- Cold spray
- Laser

E.1.1 Oxy-fuel wire spray—Flame spray

The OFW spray process (also called wire flame spraying or the combustion wire process) is the oldest of the thermal spray coating methods and among the cheapest capital investment. Acetylene or other common fuel gases are combined with oxygen and ignited in the spray gun. The coating material is usually in wire form although solid rod feed stock has also been used. During operation, the wire is drawn into the flame by drive rollers that are powered by an adjustable air turbine or electric motor. The tip of the wire is melted as it enters the flame and is atomized into particles by a surrounding jet of compressed air and propelled to the work piece (see [Figure E.1](#)).

Wire flame sprayed coatings generally exhibit lower bond strengths, higher porosity, a narrow working temperature range, and a higher heat transmittance to the substrate than plasma or electric arc spray coatings.

E.1.2 Twin wire electric arc

Electric arc wire spraying also applies coatings of selected metals in wire form. Push-pull motors feed two electrically charged wires through the arc gun to contact tips at the gun head. An arc is created that melts the wires at temperatures greater than 4000 °C. Compressed air atomizes the molten metal and projects it onto a prepared surface (see [Figure E.2](#)).

Because of the high temperatures in the arc zone, the coatings have excellent adhesion and high cohesive strength. Super heating of the particles after impact may lead to a metallurgical “weld” bond with some metals, substantially increasing adhesion and cohesive strength.

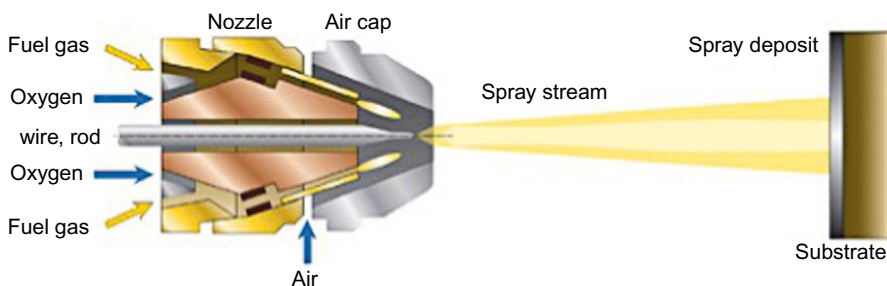


Figure E.1 Flame spray nozzle schematic.

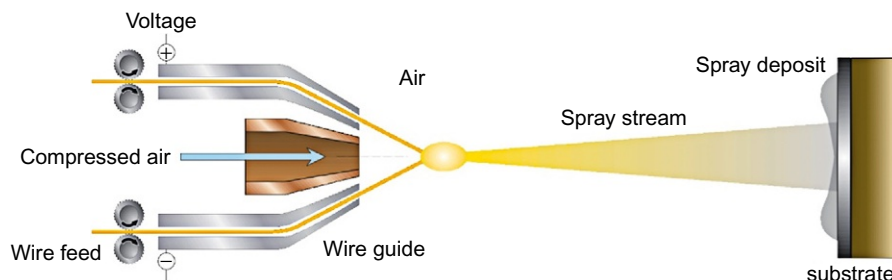


Figure E.2 Twin arc electric nozzle schematic.

E.2 Use of organic topcoats

Organic sealers or topcoats are used but are not essential over the thermally sprayed metal to extend the life of the system. Common sealers include many of the synthetic resin coating systems, especially vinyls, epoxies, polyurethanes, and phenolics. Most sealers are applied in at least two coats, the first of which is thinned for penetration into the pores of the thermally deposited metal coating. The second and sometimes third coats of a sealer are applied undiluted to build coats.

Because there are no solvents or volatile material in any metallic thermal spray system, VOC compliance is not a problem. However, VOC compliance may be an issue if an organic sealer coating is used.

E.3 Application strategies

TSA can be applied to all equipment fabricated from carbon manganese and low alloy steel and, if required, to both austenitic and duplex stainless steels. The application is more economic when applied to new equipment in dedicated fabrication shops but TSA can also be applied in the field in maintenance or project facilities and directly onto piping/equipment in situ. TSA is, therefore, applicable for similar applications as paint and conventional coatings.

- Off-site, on all new fabrications (vessels, tanks, piping, etc.)
- Off-site, or in the field on all new fabrications
- Off-site, in maintenance areas (equipment removed from service)
- On-site, during maintenance turnarounds (equipment taken out of service)
- On-site, on equipment taken out of service while the rest of the plant is running
- On-site, on live equipment

Procedures and application specifications need to be developed for TSA application in the field, especially when application on live equipment containing flammable hydrocarbons is considered. Generally, OFW coatings are preferred over TWEA for

site TSA application on piping and vessels with limited access. This is based on experience which shows that OFW coatings are easier to apply and have lower SHE related issues. The bond strength of OFW TSA is generally lower than the bond strength of TWEA TSA coatings but is nonetheless considered more than acceptable from a Fitness for Purpose perspective. This is also true for live equipment applications because of the less stringent permit procedures that are required. TWEA spray has a higher application rate than OFW in less congested areas such as large tanks and other large equipment which can be used to lower the overall cost of application. Selection of the TSA application process for shop-applied applications should be made following an economic assessment.

E.4 TSA specification

This specification outlines the requirements for the protection of externally insulated vessels and piping surfaces from CUI by the application of TSA.

- The extent of TSA coating shall include all vessel/pipe work surfaces including nozzles, brackets, attachments, insulation support rings, etc. Vessel skirts/saddles shall also be TSA coated when applicable and identified accordingly in contract documentation.
- This specification covers both on- and off-site TSA application.
- Excluded from this specification are details of the safety issues involved with the TSA process. This shall be contained in other contract documentation.

E.5 Definitions

Definitions of terms used in this specification are provided in [Table E.1](#).

Table E.1 Definitions

Client or Owner	The eventual equipment owner
Contractor	The actual company carrying out the work
Coating Contractor	The company responsible for the defined piece of coating work, including the supply of the materials
Manufacturer	The manufacturer of the coating materials
Supplier	The supplier of the item requiring coating, which may or may not necessarily be the Coating Contractor
Shop	Preparation and coating of new, bare steel surfaces in a Supplier's or Coating Contractor's shop or plant works prior to transportation to the site of construction, or a controlled environment coating facility erected at the permanent site of construction

E.6 Referenced codes, standards, and specifications

The latest revisions, unless otherwise stated, of the standards and codes of practice listed in [Table E.2](#) shall apply where relevant to work covered by this specification.

E.7 Coating philosophy

- The application of the TSA systems shall only be performed by approved Coating Contractors.
- The Coating Contractor operator qualifications should be evaluated to DIN EN ISO 14918, AWS C2.18 or AWS C2.23, or Client agreed equivalent.
- Coating Contractor to provide operator experience list and TSA procedures for Client/ Contractor review and agreement prior to contract award.

Table E.2 Referenced standards and codes

DIN EN 657	Thermal spraying terminology, classification
DIN EN 582	Determination of the tensile adhesive strength of thermally sprayed coatings
DIN EN 13507	Thermal spraying pre-treatment of surfaces of metallic parts and components for thermal spraying
DIN EN 15520	Thermal spraying recommendations for constructional design of components with thermally sprayed coatings
DIN EN ISO 2063	Thermal spraying metallic and other inorganic coatings Zn–Al and their alloys
DIN EN ISO 14918	Thermal spraying approval testing of thermal sprayers
ISO 8501-1	Preparation of steel substrates before application of paint and related products. Visual assessment of surface cleanliness
ISO 8502-3	Preparation of steel substrates before application of paint and related products. Test for the assessment of surface cleanliness. Part 3 assessment of dust on the steel surfaces prepared for painting (pressure-sensitive tape method)
ISO 8503	Preparation of steel substrates before application of paint and related products. Surface roughness characteristics of blast cleaned substrates
ISO 209-1	Wrought aluminum and aluminum alloys. Chemical composition and forms of products. Part 1: chemical composition
AWS C2.18	Guide for the protection of steel with thermal sprayed coatings of aluminum and zinc and their alloys and composites
AWS C2.23	Specification for the application of thermal spray coatings (metallizing) of aluminum, zinc, and their alloys and composites for the corrosion protection of steel

- Qualifications and details shall only be submitted for those operatives designated to perform the production work: additional and/or replacement operatives shall not be used without agreement from the Client/Contractor following review of their qualifications and experience details.
- Direct evaluation of work carried out by the applicator on comparable equipment that has operated for at least a full year should be conducted where possible.
- Subject to review of the Contractor and operative documentation, the Client/Contractor may require practical qualification tests, as defined in AWS C2.18 Appendix C, to be carried out by the operatives designated to perform the production work.

E.8 Coating system

- Coating thickness readings shall be taken by the Coating Contractor and/or Supplier. The Client and Contractor will conduct selective quality checking by taking independent coating thickness readings.
- Readings shall be done using any single minimum/maximum method. The frequency of the single point readings shall be agreed upon with the Client.
- Ordinary Coating Thickness Gauge can be used. Readings from the anchor pattern must be recorded before coating for later deduction from coating readings.
- The frequency/location of the thickness checks shall be proposed by the Coating Contractor and included in the submitted Quality Plan.
- The blast anchor pattern readings shall be taken by the Coating Contractor in accordance with his Client/Contractor agreed Quality Plan.
- The acceptable pull off adhesion test value is 6.9 Mpa (1000 psi), minimum for new test plate (Table E.3).

Table E.3 TSA surface preparation

Surface preparation	Coating system	Thickness range
Cleanliness: ISO 8501 Sa 2½ Roughness: ISO 8503 grade medium G (75 µm minimum)	Thermally sprayed aluminum with or without seal coat	200–250 µm (excluding sealer)

E.9 TSA material

- The material for metal spraying shall be commercially pure aluminum with an aluminum quality at least equal to AL 99.5 of ISO 209-1. Use of other alloys should be reviewed with the Client prior to application.
- All metals shall be supplied with product data sheets and quality control certificates, and be marked with the metal manufacturer’s name, manufacturing standard, metal composition, weight, and manufacture date.

E.10 Seal coat

The addition of seal may be required and will be specified on a case-by-case basis by the client. To enable the Client to make the decision, the Supplier and/or Coating Contractor shall supply the following details with his bid documentation:

- Specification, including thickness, and data sheets for proposed seal coat. (Temperature range for sealers should be as stated.)
- Time to apply the seal coat per vessel and/or piping system.
- Cost per vessel and/or piping system for applying the seal coat.
- The temperature range of proposed seal coat material should follow [Table E.4](#).
- The seal coat material shall be compatible with the substrate and approved by the Contractor and Client. Aluminum and titanium dioxide pigments aid sealer performance while alkaline materials such as sodium silicate will damage it.
- The sealer shall be applied until the absorption is complete. In the case of an epoxy sealer, apply one thinned coat to get optimum penetration, followed by a second coat of the same material without thinning.

E.11 Design

- Welds shall not be coated until all approved heat treatment, non-destructive testing, and pressure testing has been completed and approved.
- Certificates of release, confirming that successful completion of all appropriate tests and safety checks have been carried out to the released working areas, shall be obtained before the commencement of coating work.
- The following items shall be shielded and protected to prevent damage during surface preparation and coating material application operations. All openings, including those that are flanged or threaded shall be sealed to prevent entry of blast abrasive or coating material. After completion of coating operations all material used for shielding and sealing shall be removed unless instructed otherwise.
 - Nameplates
 - Packing glands and seals
 - Vents
 - Valve stems
 - Instrument dials
 - Gauge and flow indicator glasses
 - Pressure gauges
 - Machined surfaces of gasket contact surfaces

Table E.4 Sealer temperature range

Surface temperature
–20 °C minimum to 120 °C maximum
120 °C and greater

E.12 Surface preparation

- The Coating Contractor shall grit blast the vessel and/or surface to EN-ISO 8501 Grade Sa2½ (Near White Blast Finish).
- An anchor pattern of 75 µm minimum shall be achieved using an angular grit.
- The abrasive size shall be selected to achieve a surface roughness specified to ensure the adhesion of the sprayed coating and shall be more coarse than normally used for painting.
- Abrasive blast cleaning employing sand or slag abrasive from mineral smelting is not permitted.
- The abrasive shall be clean and dry, and free from soluble salts.
- The surface shall be dust free prior to application of the thermal spray coating.
- The Coating Contractor shall consider how big an area to blast prior to applying the TSA coating (i.e., how long the blast will hold), and include this in his overall coating plan.

E.13 Weather and surface conditions

Surface preparation and coating shall not be undertaken when any of the following conditions exist:

- Conditions favorable to surface condensation
- The relative humidity is above 85%
- There is the likelihood of a change in weather conditions within 4 h of the application which would result in air temperatures below those specified or the deposition of moisture upon the surface.
- Metal surfaces having temperatures less than 3 °C above the dew point.

E.14 Application process

- The application process may be OFW or TWEA.
- The preferred material feed mechanism for in-field application is wire feed. Powder feed mechanisms are acceptable alternatives for shop applied work but must be approved by Client for site application.
- The spray pattern should be in block form layer and shall overlap on each pass of the gun. The coat shall be applied in multiple layers at right angles to the previous layers (box pattern).
- The success of TSA application is greatly dependent on the application technique, head travel speed, and the distance from the surface being coated. The application technique shall be detailed in the Coating Contractor's application procedure and verified and monitored by the area foreman during the application process.
- The sprayed coating should be visibly free of lumps, blisters, and loosely adhering particles.
- When applying TSA, production test plates shall be prepared for the purpose of adhesion testing during the TSA application process. The test plates shall provide similar geometrical complexity to the item to be coated, shall be prepared and coated concurrently with the item, and supplied one per shift. The plates shall be approx. 300×300×6 mm. The panel shall be blast cleaned and TSA coated in such a manner as to show both processes equally split over one face of the panel. On completion of coating, the panel three adhesion tests shall be carried out to EN 582, ISO 4624 and measured against the requirements of this specification.

E.15 Specific requirements for on-site TSA application

- Grit blasting and TSA coating application shall avoid damage to gaskets, cables, instruments, valves, etc. by using appropriate sheeting/shielding. The design of the sheeting/shielding shall be agreed upon between Coating Contractor, Contractor, and Client.
- The Coating Contractor, in general, is responsible for sheeting instruments, etc. using fire retardant sheeting. However, a site visit prior to application will reveal any areas where the Client will be required to assist with protection/removal for access. The protection of these items should be inspected and approved by the Client before grit blasting and thermal spraying commences.
- The Coating Contractor shall grit blast surfaces using a vacuum type process when requested by the Client.

E.16 Piping field welds

- The surface finish shall be as close to ISO 8501 Grade Sa2½ (Near White Blast Finish), as practical, using angular grit.
- The anchor pattern shall be as close to 75 µm as practical.
- Slag abrasive from mineral smelting shall not be used.
- Moisture shall not be present on the steel surface and spraying should not take place when the steel temperature is less than 3 °C above the dew point. Existing TSA coating of pipe work to be feathered back a minimum of 100mm before new coating applied. Care should be taken not to apply new TSA coatings to seal coated surfaces.
- Full QA documentation is not required for this process, but coating thickness readings shall be marked on the adjacent pipe for checking.

E.17 Inspection and acceptance

Before commencement of work, the Coating Contractor shall determine witness/hold points for examination of the following areas during the work:

- Qualification records before starting work.
- Witnessing of test plates for individual operators. This will include surface profile after grit blasting, pull off tests, bend tests, and thickness tests.
- Surface preparation/profile before applying metal coating.
- Metal coating before applying seal coat.
- Seal coat after dried or cured to permit handling (if applied).
- The Coating Contractor shall be responsible for inspection and tests including all tools needed for quality control.
- Any areas identified as being below the requirements of this specification shall be corrected immediately. Repair/correction methods shall be Client/Contractor agreed.
- Client/Contractor reserves the right to inspect all phases of shop and field cleaning, surface preparation, and coating operations to ensure that the Coating Contractor is accurately following the recommendations and requirements of this Project Specification and the Manufacturer's instructions. This inspection shall not be used as a substitute for adequate Coating Contractor supervision and inspection nor the Coating Contractor's own quality assurance and quality control systems and procedures.

- Coating Contractor shall keep an accurate daily record of air temperatures and humidity conditions and the time of commencement and cessation of all phases of cleaning, surface preparation, and TSA operations. These records, which shall be certified accurate by the Coating Contractor's painting supervisor, shall be available for inspection by Contractor at all times.
- Final acceptance will be by the Client and will only be made a minimum of 24 h after the application to allow rust bloom of any low thickness areas to develop. The Client may, at their discretion, request the equipment be sprayed with fresh water to accelerate this process if considered necessary. Any areas found with rust bloom after this period and found to have a coating less than that required in this specification, shall be grit blasted and recoated to the satisfaction of the Client.
- Failure by the Client's Inspector to detect a deficiency, or waiver of Client Inspection, does not relieve the Coating Contractor of responsibility for quality or performance of the coating as required by contract. Testing and inspection shall be in accordance with the requirements listed in [Table E.5](#).

Table E.5 Testing and inspection requirements

Test type	Method	Frequency	Acceptance criteria	Consequence
Environmental conditions	Ambient and steel temperature Relative humidity Dew point	Before start of each shift + a minimum of twice per shift	In accordance with specified requirements	No blasting or coating
Visual examination of substrate	Visual for sharp edges, weld spatter, slivers, rust grade	100% of all surfaces	No defects	Defects to be repaired
Cleanliness	ISO 8501-1 ISO 8502-3	100% visual of all surfaces Spot checks	ISO SA2½ Max. quantity and size rating 2	Re-blasting, Re-cleaning, and re-testing until acceptable
Roughness	Testex Press-O-Film, X-coarse 37–113 µm replica tape	Once per 2 m ²	75 µm (min)	Re-blasting
Visual examination of coating	Visual	100% of surface after each coat	Surface shall be uniform and free of lumps, loosely adherent spattered metal, bubbles, ash formation, defects, and uncoated spots	Repair defects

Table E.5 **Continued**

Test type	Method	Frequency	Acceptance criteria	Consequence
Coating thickness	Single point maximum/minimum	To be agreed with Contractor and Client	200–250 µm minus surface profile	Repair, additional coats or re-coating as appropriate and approved by Contractor and Client
Adhesion	ISO 4624 using equipment with an automatic centered pulling force, and carried out when fully cured	Each test plate—on new steel	6.9 MPa minimum	Coating to be rejected

E.18 Documentation

- Coating Contractor shall submit procedures with their tenders for application process, operator qualification/training, and Quality for Client/Contractor agreement. A Control Plan, preferably to AWS C218 or AWS/SSPC CS 2.23, is required for review and agreement prior to contract award.
- The final coating documentation package shall include operating parameters of equipment, application operative’s name, blast profile, TSA dry film thickness measurement data, pull-off test results, and application environmental condition data.

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Appendix F: Insulation material types and forms

The most commonly used industrial insulation materials are described below. Generic references to the thermal insulation materials like glass wool, mineral wool, mineral fiber, etc., shall be interpreted in accordance with the definition given in ASTM C547, ASTM C612, BS 3958 Part 4, and BS 3958 Part 5 (as man-made mineral fiber made from rock, slag, or glass, processed from a molten state into a fibrous form with a suitable binder). For the purposes of this document, materials of a rock composition (diabase, silica ore, basalt, or similar types) shall be acceptable. Materials made from slag (in part or in whole) shall not be acceptable. Fibrous materials made of glass shall only be permitted where specified as expansion joint filler.

F.1 Mineral fiber

ASTM groups commercial glass and mineral rock, stone, or ceramic fiber materials into a single category—generally described as rocks, slag, or glass processed from a molten state into a fibrous form with organic binders. Mineral fiber is generally specified for ambient to high temperature, the upper temperature being dependent on the specific fiber and binder used. Most common available types are glass-wool, rock-wool, and high temperature materials like silica and micro porous silica.

Both the water absorption characteristics and the ability to repel water are variable and are dependent on the specific fiber and binder used. Some binders may break down in the presence of heat and water, which leads to wicking.

Preformed mineral fiber insulation shall be of a rock composition complying with physical characteristics listed in BS 3958: Parts 4 and 5, and where these do not conflict, physical characteristics listed in ASTM C612, and C547 or EN 143030. The material shall be a water repellent grade complying with the following overriding requirements:

Combustibility: Non-combustible when tested in accordance with BS 476: Part 4, ASTM E136, or ISO 1182.

Water absorption: Max 10 vol% according ASTM C612 or 1 kg/m² according EN 1609.

Chemical requirements: Less than 10 ppm chloride, and less than 10 ppm fluoride, when tested in accordance with ASTM C871 or EN 13468; with a combined halide content no greater than 15 ppm. All material shall be qualified for use on austenitic stainless steel in accordance with ASTM C795 by conforming to the pre-production test requirements of ASTM C692 and the confirming quality control requirements for chemical analysis of ASTM C871. These standards require 50 ppm sodium silicate for up to 20 ppm chloride.

Shot content: Less than 6% by weight of shot exceeding 250 µm when tested in accordance with Section 14 of BS 2972, and less than 31% by weight of shot/coarse fibers between 63 and 250 µm.

Content of sulfur compounds: Less than one half percent by weight.

Alkalinity: pH of between 7 and 10.5 when tested in accordance with ASTM C871 EN 13468.
Optimum service temperature range: 20–650 °C.

Thermal conductivity: No greater than that listed in Table F.1, when tested in accordance with Section 4 of BS 2972.

Water retention: When tested in accordance with an authoritative modification to Section 12 of BS 2972 approved by the Engineer (covers test specimens of preformed pipe section, nominal pipe size (NPS) 250 mm [25 mm thick × 25 mm deep]) as well as the flat slab sample specified in the BS 2972. The maximum acceptance values listed in Table F.2 all be achieved.

Binder: Resin impregnation during manufacture prior to compressing and curing.

Proportion of fine fibers: 31% or less of fibers less than 3 µm diameter in the bulk fibrous material.

Facings for flexible mattresses: Facings shall comprise 0.9 × 25 mm mesh wire netting sewn with wire ties at close regular intervals in such a way as to ensure that these cannot be pulled through during storage, handling, and fabrication. The wire mesh shall be stainless steel for application to stainless steel vessel heads and galvanized for other applications. The facing shall be on both sides.

Dimensional tolerances: Tolerance on thickness, length, and inside diameter shall conform to requirements of BS 3958: Part 4 or, ASTM C547.

The following minimum densities and forms of preformed mineral fiber pipe sections and slabs shall be used as first and second layers up to 500 °C, and as second and third (outer) layers only, for temperatures above 500 °C:

Piping: Pipe sections 125–155 kg/m³ density, either in two halves or in one piece hinged (snap-on) for all sizes up to maximum commercially available pipe size. For larger diameters, factory cut beveled lags of 140 kg/m³ density shall be employed.

Heat traced piping: Pipe sections as for piping but oversized, generally up to the next commercially available size, to accommodate parent line and its accompanying tracer.

Table F.1 Thermal conductivity of mineral fiber insulation

K value (W/mK)	
Mean temperature (°C)	Thermal conductivity of a slab or sections of mattresses (W/m K)
50	0.037
100	0.044
150	0.052
200	0.061
300	0.082
350	0.096
400	0.111

Table F.2 Water retention in mineral fiber insulation

Partial immersion	Total immersion
0.2 kg/m ² at 20 °C	20 kg/m ³ at 20 °C
0.2 kg/m ² at 250 °C	20 kg/m ³ at 250 °C

Equipment having a diameter up to maximum commercially available pipe size: Pipe sections as for piping.

Vertical equipment having a diameter exceeding maximum commercially available pipe size: Beveled lags/rigid slabs 140 kg/m^3 for all single, inner, and outer layers.

Horizontal equipment having a diameter exceeding maximum commercially available pipe size: Beveled lags/rigid slabs 120 kg/m^3 for all single, inner, and outer layers.

The following nominal densities of preformed mineral fiber mattresses shall be used:

Flexible mattresses for equipment heads: $125\text{--}138\text{ kg/m}^3$ for all operating temperatures.

Note: Nominal densities of mattresses shall exclude metallic facings and shall be within a tolerance of 15% as per Section 7.2 of BS 3958: Part 3.

For hot face temperatures up to 650°C , the concentration of organic bonding material for all specified insulation densities shall not constitute a fire risk through the incidence of welding sparks or through an internal self-heating phenomenon (punking) over the range of insulation thicknesses and individual layers proposed by the Engineer. The manufacturer of the material shall demonstrate to the requirements of Section 18 of BS 2972 that the degree of self-heating does not exceed safe limits.

F.2 Low density glass fiber

Low density glass fiber blanket (unfaced) for packing voids or for introduction at expansion/contraction joints shall be manufactured from long continuous textile type glass fibers chopped into 50–100 mm lengths and firmly bonded in random orientation with an inert thermosetting resin. The material shall have the following minimum properties:

- Density: $23.0\text{--}24.0\text{ kg/m}^3$
- Thermal conductivity: no greater than 0.034 W/mK at 25°C mean temperature when tested in accordance with ASTM C177
- Service temperature: up to 230°C

The 100% glass fiber matt for lining reusable insulation covers as per 7.8. and for introduction at expansion joints above 230°C , shall be composed of E-glass fibers in the form of a web which is needled together without chemical binders and with a low ($<10\text{ ppm}$) chloride level. The material shall have the following minimum properties:

- Density: $140\text{--}150\text{ kg/m}^3$
- Thermal conductivity: no greater than 0.058 W/mK at 150°C mean temperature when tested in accordance with BS 874
- Service temperature: up to 500°C

F.3 Calcium silicate

Calcium silicate preformed or cut from blocks, insulation shall comprise reacted hydrous calcium silicate containing well-opened, asbestos-free reinforcing fiber.

Table F.3 Thermal conductivity of calcium silicate

Mean temperature (°C)	K value (W/mK)
050	0.055
100	0.058
150	0.063
200	0.069
250	0.075
300	0.083
350	0.092

It is hygroscopic and readily absorbs water. The material shall comply with BS 3958: Part 2 or ASTM C533 or EN 14306 and the following additional requirements:

- *Combustibility*: Non-combustible when tested in accordance with BS476: Part 4.
- *Chemical requirements*: All material shall be qualified for use on austenitic stainless steel in accordance with ASTM C795, by conforming to the pre-production test requirements of ASTM C692 and the confirming quality control requirements for chemical analysis of ASTM C871. These standards require 50 ppm sodium silicate content for up to 20 ppm chloride.
- *Water absorption*: Max. 3 vol% in accordance with ASTM C533.
- *Optimum service temperature range*: –150 to 730 °C.
- *Thermal conductivity*: No greater than that shown in [Table F.3](#) when tested in accordance with BS 874.
- *Bulk density*: 190–240 kg/m³.
- *Flexural strength*: Not less than 500 kN/m².
- *Compressive strength (cold)*: Not less than 1300 kN/m² load at onset of disruption in dry state, with a reduction in thickness no greater than 2% under a compressive load of 700 kN/m² in dry state and no greater than 5% under a compressive load of 400 kN/m² after 24 h immersion in water.
- *Linear shrinkage*: No greater than 1.6% after 24-h heat soak at 730 °C.
- *Dimensional tolerances*: Tolerances on thickness, length, and inside diameter shall conform to requirements of BS 3958: Part 2, or ASTM C533.

F.4 Cellular glass

Cellular glass shall conform to the requirements of ASTM C552, and/or ASTM C240 or EN 14305. It is a rigid block material without binder that has been foamed under molten conditions to form a closed cell structure having properties associated with the lighter density/lower thermal conductivity Type T4 material, as follows:

- *Rigid cellular glass*: Factory shaped/cut into slabs, radiused and beveled segments, and half pipe sections.
- *Density*: Average 120 kg/m³ ± 10%, measured per ASTM C303.
- *Thermal conductivity*: No greater than 0.039 W/(mK) ± 10% at 10 °C, measured per ASTM C177.
- *Compressive strength*: Average 700 kPa when capped with hot asphalt, measured per ASTM C165.

- *Chemical requirements:* Less than 10 ppm chloride, when tested in accordance with ASTM C871 or EN 13468; and less than 10 ppm fluoride, with a combined halide content no greater than 15 ppm. The material shall be qualified for use on austenitic stainless steel in accordance with ASTM C795 by conforming to the pre-production test requirements of ASTM C692 and the confirming quality control requirements for chemical analysis of ASTM C871. These standards require 50 ppm sodium silicate content for up to 20 ppm chloride.
- *Water vapor permeability:* Zero measured per ASTM E96 procedure A or EN 12086.
- *Closed cells content:* 100% according to ASTM D2856.
- *Linear coefficient of thermal expansion:* $9.0 \times 10^{-6}/K$ per ASTM E228.
- *Combustibility:* Non-combustible per ASTM E84.
- *Modulus of elasticity:* 800 MPa: measured per ASTM C623.
- *Alkalinity:* pH between 7 and 10.5 per ASTM C871 or EN 13501-1.
- *Dimensional tolerance on length:* ± 2.0 mm.
- *Dimensional tolerance on thickness:* ± 2.0 mm.

For pipe sizes up to 450 mm diameter, the tolerances on thickness are in addition to permitted variations in thickness, where these are determined by the manufacturer's economic cutting program, designed to ensure that the outside diameter of the cellular glass always corresponds to the outside diameter of a standard pipe. This results in thickness variations of +9 to -3 mm according to pipe size.

- *Dimensional tolerance on inside diameter:*
 - +1.0 to +2.0 mm for half shells with ID < 38 mm
 - +1.0 to +3.0 mm for half shells with ID > 38 mm
 - +2.0 to +5.0 mm for segments
- *Concentricity:* Maximum deviation 3.2 mm or 5% of wall thickness, whichever is greater.
- *Thickness range:* Minimum thickness 25 mm, maximum thickness 120 mm per layer. For thicknesses greater than 120 mm or where the temperature gradient through any individual layer is in excess of 120 °C, multi-layer construction shall be used.
- *Length:* All pipe sizes, minimum length 600 mm.
- *Availability in half sections:* Insulation shall be supplied as cylindrical sections split into half sections for all pipe sizes up to 450 mm diameter over insulation. For larger pipe sizes, insulation shall be supplied as radiused and beveled segments.
- *Fabrication standards:* For all pipe sections fabricated for sizes exceeding 300 mm and not exceeding 450 mm diameter over insulation and for all radiused and beveled segments, cellular glass may be cut from stacked blocks using a fabrication adhesive and with minimum number of insulation blocks consistent with economic utilization of the material. For this purpose, each full section of insulation shall contain not more than four "through" joints, excluding the half section mating plane. No segment shall, as a result of cutting, be less than 25 mm thick at the highest point of the arc.
- *Fabrication adhesive:* For jointing of stacked blocks during fabrication of pipe sections, the grade of adhesive to be used for operating temperatures above ambient shall be a gypsum cement adhesive with a leachable chlorides content of max. 90 ppm according to ASTM C871. This also goes for the anti-abrasion bore coating.
 - *Adhesive coverage:* Fabrication adhesive shall be applied such that there is 100% coverage of adhesive and mating surfaces. In addition, there shall be no visible voids in the adhered joint nor shall any adhered joint exceed 1.6 mm in width.
- *Fabrication facilities:* Shop fabrication of cellular glass pipe sections, segments, and fittings shall be by a pre-qualified and approved fabricator.

F.5 Ceramic fiber paper

Ceramic fiber paper is used for initial wrapping of piping and equipment containing corrosive fluids, and for similar wrapping of instruments and instrument leads where full contact with steam tracing is not required (classified as light tracing). It shall be a 1.0 mm material in 10 m long $\times$ 1.0 m wide rolls, containing a minimal quantity of organic binder.

F.6 Glass rope insulation

Glass rope insulation, for wrapping small bore piping and valves, shall consist of unbonded, braided E-glass fibers enclosed in a braided cover of glass yarn, and be sufficiently robust to ensure stability during application and in service. The rope shall be resilient and suitable for operating temperatures up to 540 °C.

F.7 Self-setting cement

Self-setting cements are used to join insulation materials into useful shapes. Hydrated silicates are used in conjunction with calcium silicate, perlite, and cellular glass to form an intimate mixture of non-asbestos inorganic mineral fibers. These form a general purpose protective coating suitable for trowel or hand application and with fast setting properties without the application of heat. The material shall produce a robust surface layer having breather type weather resistant properties and resistant to impact and abrasion damage, with a temperature limit not less than 175 °C for continuous service conditions. When dried out, the cement shall be free from cracking other than fine hairline cracks.

F.8 Flexible reusable insulation cover mattresses

Individually tailored, flexible, reusable insulation cover mattresses for flanged joints, valves, and instruments should be shop fabricated. Because type, manufacturing methods, choice of fabrics and filler materials, and details like closing mechanism vary per country and region we only state the CUI relevant properties. These should be in conformance with the following:

- Mattresses should be designed, manufactured, and installed in such a way that no moisture, condensate, or ingressed water can be captured in voids or lower parts of the mattress.
- *Outer cover throughout:* Heavy duty satin weave E-fiberglass fabric silicone rubber or PTFE impregnated on both sides, completely waterproof, UV resistant, and temperature resistant up to 260 °C (continuous) and having a weight of 560 g/m², including 150 g/m² silicone. E-glass shall be resistant to oils, fats, solvents, organic acids, and substances having pH values in the range of 3–9.

- *Inner cover up to 260 °C:* Heavy duty satin weave fiberglass fabric, silicone rubber or PTFE impregnated on one side, water resistant, UV resistant and temperature resistant up to 260 °C (continuous) and having a weight of 500 g/m², including 90 g/m² silicone. E-glass shall be resistant to oils, fats, solvents, organic acids, and substances having pH values in the range of 3–9.
- *Inner cover above 260 °C:* High purity silica fabric 610–1085 g/m².
- *Insulation lining:* Unbonded, needled, type-E glass fiber matt 140 kg/m³ density at 25 mm thickness, having low chloride level and no resinous or organic binders.
- *Side extensions:* Single thickness outer cover extensions with heavy duty drawstrings to effect end closure over adjacent pipe insulation. Drawstrings shall be 4.8 mm diameter solid braid Nomex, with ends cauterized to prevent raveling.
- *Protection at hot protrusions:* Double thickness inner/outer cloth laps to obtain a weather and heat resistant seal. Above 260 °C, inner cover material carried over edges with box seams are sufficient to ensure integrity of outer cover material while remaining weather tight.
- *Retention:* Velcro incorporated at overlaps, also fully effective easily releasable straps/stainless steel buckles.
- *Sewing thread:* Teflon coated glass for fabrication up to 400 °C and stainless steel thread above this temperature.

F.9 Preformed rigid polyurethane foam (polyurethane-polyisocyanurate)

- Polyurethane (PUR) is made by the polymerization of an isocyanate resin to create a plastic material with a wide range of properties. Reaction between the isocyanate (polymeric methyl diphenyl isocyanate or MDI) with certain types of polyol, such as a polyether, creates a tough but rigid plastic material.
- Polyisocyanurate (PIR) is an improved type of rigid PUR. The production process creates strong isocyanurate linkages in the molecular structure. Chemical breakdown of the foam occurs at higher temperatures than PUR, so it is much more difficult to ignite. True PIR foam contains about 50% or more isocyanurate linkages.
- The material shall be supplied as slabs, radiused and beveled segments, and as pipe sections precision cut from fully cured bun stock. The material shall be factory coated with a mylar or equivalent foil and shall have the following properties:
 - Core density: Not less than 40 kg/m³, measured per ASTM D1622.
- Thermal conductivity measured per ASTM C177 on 25 mm thick foam, cut on both sides and aged at 21 °C for 180 days shall be no greater than that shown in [Table F.4](#).
- The thermal conductivity for freshly blown foam shall be no greater than 0.019 W/(mK).
- Cell structure: In accordance with ASTM C5914 or EN 14308, uniform and free from major voids and bubbles in excess of 1.5 mm diameter across the rise or 5 mm in depth in direction of rise, and no more than five smaller voids or bubbles per 250×250 mm area on any cut standard length of half pipe section, lag, or slab.
- Closed cell content: Minimum 90% by volume on average with a minimum of 85% by volume for any sample, measured per ASTM D6226 procedure 2 and in accordance with EN ISO 4590 min. 90%.
- Compressive strength: Not less than 160 kPa perpendicular to rise and 240 kPa parallel to rise measured per ASTM D1621 at ambient temperature.

Table F.4 Thermal conductivity of preformed rigid polyurethane foam (PUR/PIR)

Mean temperature	Thermal conductivity (W/mK)
20	0.023
0	0.022
−20	0.024
−40	0.023
−60	0.021
−80	0.019
−100	0.018

- Fire resistance properties:
 - BS 476 Part 7: Class 1 surface of very low flame spread. ASTM E84. Maximum flame spread rating of 25.
 - ASTM D3014. 85% retention of weight (Butler chimney test).
 - US Bureau of Mines Test—flame penetration 20 min.
- Linear coefficient of thermal expansion $40\text{--}80 \times 10^{-6}$ per °C according to direction per ASTM E228.
- Water vapor transmission at 38 °C and 100% RH: 21.6 µgm/Nh measured per ASTM E96.
- Alkalinity: pH of between 7 and 9 per ASTM C871 or EN 13468.
- Maximum leachable chloride content: 60154 ppm per ASTM C871 or EN 13468.
- Dimensional tolerance on length: + 2.6 mm over 1.0 m length.
- Dimensional tolerance on thickness: +1.6 mm for single layer application and +1.6 mm on the overall thickness of assembled layers for multi-layer application.

F.10 Flexible elastomeric foam

FEF with a closed cell structure and manufactured from a natural or synthetic rubber or a combination thereof, in accordance with ASTM C534 or EN 14304. FEF rubber can be made of NBR type or EPDM type.

- *Temperature range:*
 - *Sheets* from 85 to −40 °C.
 - *Tubes* from 105 to −40 °C (high temperature materials, 145 °C).
- *Density:* 50 kg/m³ in accordance with ASTM D 1622.
- *Thermal conductivity:* in accordance with ASTM C-177 ([Table F.5](#)).
- *Closed cells* content: 90% in accordance with ASTM D 2856, D 1056 or EN 12087.
- *Water vapor permeability:* Maximum 0.007 g/(m²h) at 23 °C and 50% relative humidity in accordance with ASTM E96, procedure A.
- *Mechanical properties:* The dimensional stability of FEF is not affected by moisture.
- *Chemical properties:* Leachable chlorides content max. 90 mg/kg. in accordance with ASTM C871, procedure 2 or EN 13468.
- *pH value:* between 6.0 and 8.0. In accordance with ASTM C 871.
- *Ultraviolet-radiation:* FEF is not resistant to UV-radiation. This also applies when it is used directly under glass in full light.
- *Combustibility:* Flame spread index <25, in accordance with ASTM E84 (locally, different fire requirements may apply).

Table F.5 Thermal conductivity of flexible elastomeric foam

Average material temperature (°C)	Thermal conductivity (W/mK) ^a —max.
20	0.037
10	0.037
0	0.036
−10	0.035
−20	0.034

^a These values are based on measurements performed by an independent institute and apply to the field for which the material is used.

F.11 Flexible elastomeric foam (EPDM)

FEF with a closed cell structure and manufactured from selected synthetic rubber, in accordance with ASTM C534.

- *Temperature range:*
 - *Sheets and tubes:* 125 to −55 °C.
- *Density* in accordance with ASTM D 1622: 60–90 kg/m³.
- *Thermal conductivity:* In accordance with ASTM C177 (Table F.6).
- *Closed cells* content in accordance with ASTM D2856: 95%.
- *Water vapor permeability:* In accordance with ASTM E96, procedure A: max. 0.007 g/(m²h) at 23 °C and 50% RH.
- *Mechanical properties:* The dimensional stability of EPDM is not affected by moisture.
- *Chemical properties:* Leachable chlorides content in accordance with ASTM C871, procedure 2: max. 90 mg/kg.
- *pH value:* In accordance with ASTM C871: between 6.0 and 8.0.
- *EPDM* is resistant to UV-radiation, ozone, and is weatherproof.
- *Combustibility:* Flame spread index in accordance with ASTM E84: <25 (locally, different fire requirements may apply).

Table F.6 Thermal conductivity of flexible elastomeric foam (EPDM)

Average material temperature (°C)	Thermal conductivity (W/mK) ^a —max.
40	0.040
20	0.037
0	0.035
−20	0.034
−40	0.030

^a These values are based on measurements performed by an independent institute and apply to the field for which the material is used.

F.12 Polyethylene

Polyethylene, fillers: in accordance with ASTM C534 (Tables F.7 and F.8).

- *Cell structure*: Tested in accordance with ASTM D2856: minimum closed cell content 90%.
- *Water absorption*: In accordance with ASTM C534: 10% by weight.
- *Water permeability*: Tested in accordance with ASTM E96.
- *Water vapor diffusion resistance factor*: Tested in accordance with ASTM E96—1800.
- *Hygroscopicity*: None.
- *Capillarity*: None.
- *Dimensional stability*: In accordance with ASTM C534.
- *Longitudinal shrinkage*: 2%.
- *Diametric shrinkage*: 2%. UV resistance: Tested in accordance with ASTM D1171.
- *Leachable chlorides content*: In accordance with ASTM-871: 10 mg/kg.
- *pH value*: In accordance with ASTM C871: pH min. 6, max. 10.5
- *Combustibility*: Flame spread index in conformity with ASTM E84: <25 (locally, different fire requirements may apply).

F.13 Perlite

Perlite granulates (loose fill) consisting of expanded perlite, in accordance to ASTM C610 (Tables F.9 and F.10).

- *Melting temperature*: 900 °C.
- *Hygroscopicity*: Tested in accordance with ASTM C-390.
- *Water absorption*: Tested in accordance with ASTM 610: max. 10 vol%.
- *Compressive strength*: Not applicable.
- *Dimensional stability*: Not applicable.
- *Vibration resistance*: Not applicable.

Table F.7 Material properties of polyethylene insulation

Temperature (°C) tested in accordance with ASTM C-447	Volumetric mass (kg/m ³) tested in accordance with ASTM D-1622
20–100	30
20–100	35

Table F.8 Thermal conductivity of polyethylene insulation

Temperature (°C)	Thermal conductivity (W/mK) for 35 kg/m ³ material*
40	0.039
20	0.037

* Note: These values are based on measurements performed by an independent institute using ASTM C-177.

Table F.9 Material properties of perlite

Temperature (°C) tested in accordance with ASTM C-447	Volumetric mass (kg/m ³) tested in accordance with ASTM C-520
–272 to 760	48...72

Table F.10 Thermal conductivity of perlite

Temperature (°C)	Thermal conductivity* (W/mK)
15	0.049
–50	0.043
–100	0.037
–150	0.031
–200	0.026

* Note: Tested in accordance with ASTM C-177.

- *Linear thermal expansion coefficient:* Not applicable.
- *Brittleness:* Not applicable.
- *UV resistance:* Not applicable.
- *Leachable chlorides content:* In accordance with ASTM C871 EN 13468: 25 mg/kg.
- *pH value:* In accordance with ASTM C871: pH min. 6, max. 10.5.
- *Combustibility:* Flame spread index in conformity with ASTM E84: 0 (locally, different fire requirements may apply).

F.14 Vermiculite

This is ceramically bonded vermiculite sections, segments, and slabs with exfoliated vermiculite as the principal raw material in accordance with ASTM C516. The vermiculite shall not contain asbestos (Tables F.11 and F.12).

- *Water absorption:* Tested in accordance with ASTM C209 max. 5 vol%.
- *Compressive strength:* Tested in accordance with ASTM C165.
- *Dimensional stability:* Tested in accordance with ASTM C610.
- *Vibration resistance:* Tested in accordance with ASTM C421.
- *Linear thermal expansion coefficient:* Tested in accordance with ASTM C356.
- *Brittleness:* Tested in accordance with ASTM C203.

Table F.11 Material properties of vermiculite

Temperature (°C) tested in accordance with ASTM C-447	Volumetric mass (kg/m ³) tested in accordance with ASTM C-302
400...1000	375 (approximately 10%)

Table F.12 Thermal conductivity of vermiculite

Temperature (°C)	Thermal conductivity* (W/mK)
800	0.20
600	0.18
400	0.15
200	0.13
10	0.11

* Note: Tested in accordance with ASTM C-177.

- *Leachable chlorides content:* In accordance with ASTM C-871 or EN 13468: <5 mg/kg
6.3 pH value in accordance with ASTM C871.
- *pH value:* In accordance with ASTM C871 min. 6, max. 10.5.
- *Combustibility:* Flame spread index in conformity with ASTM E84: 0 (locally, different fire requirements may apply).

Appendix G: Cladding/jacketing materials

A number of cladding/jacketing materials are available to provide mechanical and weather protection for insulation systems. These are normally classified as metallic or nonmetallic materials. Choice is dependent on the availability, application, and cost.

G.1 Metallic cladding materials

Commonly used materials include, aluminum, aluminized steel, aluminum-zinc coated steel, and galvanized steel.

G.1.1 Aluminized steel sheeting

- *Steel sheet with an aluminum coating:* In accordance with ASTM A463M—T2M-300.
- *Aluminum layer thickness:* In accordance with ASTM A463M: 300 g/m² in total for both sides, 50 mm per side.
- *Mechanical properties:* In accordance with ASTM A463M. 3.1. The aluminum coating shall not crack, flake, or peel during mechanical processing with observance of the minimum deformation radius.
 - Sheet thickness 0.56 mm: Minimum radius = 1 × sheet thickness.
 - Sheet thickness 0.80 mm: Minimum radius = 2 × sheet thickness.
- *Chemical composition:* In accordance with ASTM A463M: [Table 4.2](#), commercial quality.
- *Corrosion resistance:* In accordance with ASTM A463M.
- Maximum surface temperature: 450 °C.

G.1.2 Aluminum-zinc coated sheeting

Steel sheet provided with an aluminum-zinc alloy layer: in accordance with ASTM A792M.

- Tested in accordance with ASTM A370.
- *Aluzinc layer:* Tested in accordance with ASTM A90 and A525M: 185 g/m² in total for both sides.
- *Mechanical properties:* In accordance with ASTM A792M. The aluminum-zinc layer applied shall not crack, flake, or peel during mechanical processing with observance of the minimum deformation radius.
 - Sheet thickness < 1.25 mm: Minimum radius = 1 × sheet thickness.
- *Chemical composition:* In accordance with ASTM A792M.
- *Corrosion resistance:* In accordance with ASTM A792M.
- *Maximum surface temperature:* 315 °C (temperatures above 315 °C cause color change. The protective action is retained at temperatures up to 700 °C).

G.1.3 Galvanized steel sheeting

Steel sheet: In accordance with ASTM A527M, tested in accordance with ASTM A370.

- *Zinc layer*: Tested in accordance with ASTM A525M: 275 g/m² in total for both sides.
- *Mechanical properties*: In accordance with ASTM A525M. The zinc layer applied shall not crack, flake, or peel during mechanical processing with observance of the minimum deformation radius.
 - Sheet thickness < 1.25 mm: Minimum radius = 3 × sheet thickness.
- *Chemical composition*: In accordance with ASTM A525M.
- *Corrosion resistance*: In accordance with ASTM A525M.
- *Maximum surface temperature*: 400 °C.

G.1.4 Stainless steel jacketing

Stainless steel sheet: In accordance with ASTM A167: type 304.

- *Mechanical properties*: Tensile strength, yield strength, and elongation: in accordance with ASTM A167.
- *Chemical composition*: In accordance with ASTM A167.
- *Corrosion resistance*: In accordance with ASTM A167 and treated in accordance with A480M.
- *Maximum surface temperature*: 900 °C (500 °C causes color change).

G.1.5 Aluminum sheeting

A number of alternative types of sheeting are available, these include:

- Flat sheeting unbacked
- Flat sheeting with a moisture barrier
- Profiled or corrugated sheeting

Aluminum sheeting of the specified thickness and profile shall be 3103 or 5005 alloy to BS 1470, or 3003 or 5005 alloy to ASTM B209 (an acceptable alternative is commercial grade alloy 1050), and of the hardness listed in [Table G.1](#).

Resistance to mechanical damage is poor so thicknesses must be increased in order to resist damage. However, the corrosion resistance is relatively high. Aluminum

Table G.1 Aluminum sheeting hardness

Type	Temper
Profile or corrugated sheets	H16
Flat rolled sheeting 0.4–0.6 mm thick	H16
Flat rolled sheeting 0.7–1.2 mm thick	H14
Flat sheets	H14

sheeting should not be used for fireproofing due to its low melting point. The maximum surface temperature is 350 °C (temperature above 150 °C causes structural deformation).

G.2 Nonmetallic materials

Plastic materials such as fiber-reinforced plastics and thermoplastic are not commonly used for jacketing because of their low melting temperatures, lack of resistance to mechanical abuse and ultraviolet radiation. However, recent developments have led to the introduction of UV-cured, fiber-reinforced materials which offer improved mechanical resistance and the ability of total containment.

G.2.1 UV-cured, fiber-reinforced materials

Laminate based on glass fiber-reinforced polyester resins, which are cured by UV-radiation offer a solution for long term weather proofing of insulation. Some benefits include:

- Watertight joints which resist heavy loads better than any cladding system.
- Adhesion and strength at terminations to prevent water ingress and resist mechanical load.
- Can also be used to seal metallic cladding, helping to overcome the inadequacies of a metallic cladding system. Adhesion to all types of metal to seal joints in metallic cladding.
- Material properties are provided in [Table G.2](#).
- *UV-resistance*: Good.
- *Resistance to (most) chemicals*: Good.
- *Combustibility flame spread index (dry)*: In accordance with ASTM E84: 20* Flame spread index (dry) in accordance with BS 476: Class 1* Flash point (flexible material) in accordance with ASTM D93: 32 °C (*Locally, different fire requirements may apply).

Table G.2 Mechanical properties of UV-cured fiber-reinforced materials

Temperature range	0–90 °C
Weight	2 kg/m ²
Bending strength	130 MPa
Tensile strength	50 MPa
Elongation at break	1%
Compression strength	125 MPa
Impact resistance	57 kJ/m ²
Temper	45 Barcol
Layer thickness	1.5 mm
Water vapor permeability ^a	0.001 g/(m ² h mm Hg)

^a Water vapour permeability in accordance with ASTM E96 procedure. Should only be used in combination with vapor barrier multiplex foil when the indicated value is exceeded for primary vapor application barriers in cold insulation systems.

G.2.2 Chlorosulfonated polyethylene

A polymeric material based on chlorosulfonated polyethylene (CSPE) offers a solution for long term weather proofing of insulation.

- Watertight joints which resist heavy loads better than any cladding system.
- Adhesion and strength at terminations to prevent water ingress and resist mechanical load.
- Can also be used to seal metallic cladding, helping to overcome the inadequacies of a metallic cladding system. Adhesion to all types of metal to seal joints in metallic cladding.
- Material properties are provided in [Table G.3](#).

Table G.3 Material properties for Hypalon (chlorosulphonated polyethylene CSPE)

Property	Test method	Typical values
Physical data		
Nominal thickness	—	1 mm
Reinforcing scrim	Glass	6.9×3.2
Density	BS 903 part 1	—
Hydrostatic resistance (psi; Mullins Burst)	ASTM D751 (method A)	233 lbs
Breaking strength (lbs force)	ASTM D751 (grab method)	107lb MD 100lb AMD
Elongation @ break (%)	ASTM D751 (grab method)	496% MD 355% AMD
Tear strength (lbs force)	ASTM D751 (tongue tear)	33 lb MD 34 lb AMD
Puncture resistance (lbs force)	FTMS 101B (method 2031)	106lb
Low temp resistance (−40 °F)	ASTM D2136	No cracks
Low temp brittleness (−40 °F)	ASTM D746 (procedure B)	No failure
Ply adhesion (lbs/in.)	ASTM D413 (machine method)	8 lb
Dimensional stability (%)	ASTM D1204 (1 h @ 212 °F)	0.5%
WVT—water vapor transmission	ASTM E96 Method BW (No. 2) (7 days)	0.75 g/m ² /24 h
Linear coefficient of thermal expansion	ASTM D864	20×10 ^{−5} per °C
Weathering data		
Ozone resistance	ASTM D1149 3PPM @ 30% strain at 40 °C for 70h BS 903 part A 43 1990 BS 903 part A 23 400h min	No cracks visible under 7× magnification No cracking No deterioration
Accelerated weathering (carbon arc)	ASTM D750	10,000h no chalking, cracking, crazing, no loss of flexibility

Table G.3 Continued

Property	Test method	Typical values
Artificial weathering (5000 h = 15 year Florida approx.)	5000 h under Xenon Weather-Ometer	Very slight crazing under 21× magnification
Artificial weathering	BS 3900 Part F3	1000 h no surface deterioration
Ultraviolet lightfast test	BS 3900 part F5	1000 h no surface deterioration rated 4/5 on grayscale
Salt spray	BS 3900 F12	1000 h no deterioration
Slit water pressure test	DIN 16938-6.3	Waterproof
Aggressive atmospheres test	DIN 500018	Fulfilled
Weather resistance test	SIA 280/9	10,000 h no deterioration
<i>Fire resistance data</i>		
Flame resistance	BS 476 part 7 BS 476 part 6 IMO MSC 61 (67) 1996 part 5	Class 1 pass Class “O” pass Pass

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Appendix H: Use of protection guards

H.1 Design considerations

It is not considered a requirement that all companies at all locations should use one design for personnel protection guards. Much will depend on individual site requirements and the experience and methods of the site's insulation contractors. With recent insights about energy savings and environmental challenges, replacement of thermal insulation by protective guards also has to be considered.

The aim of the personal protection examples shown in [Figure 5.3](#) is to eliminate the need for welding of supports and make it a task that the insulation contractors can perform using their traditional tools and skills.

- The flanges were not protected in this installation, but could quite easily be if needed. When personal protection is needed on the flanges or valves and easy access is needed for maintenance, examples (4) and (5) in [Figure H.1](#) give possible solutions.
- In higher temperature applications, or when the metal surface requires greater protection, a fiberglass insulation tape can be applied as in example (6) in [Figure H.1](#).

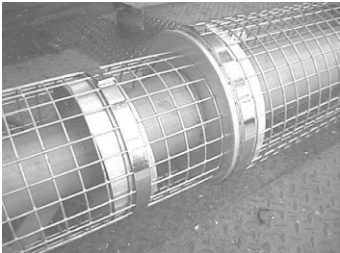
H.2 Method guidance notes

The principles and methods employed for this are very similar to fitting standard insulation cladding. A few noteworthy points are detailed:

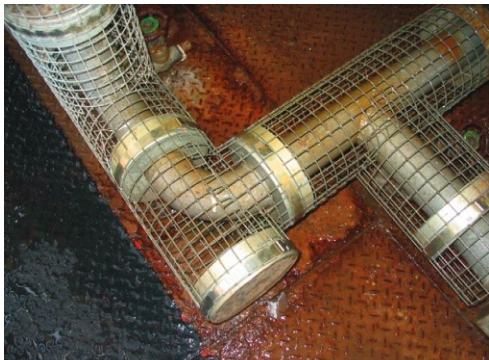
- Spacing of end caps dependent upon the risk of personnel standing or falling on it.
- Mesh rolled to shape as per normal cladding, 50 mm of overlap allowed.
- Mesh cut to shape using normal cladding patterns.
- "Stand off" of mesh from 50-mm pipe.
- Fiberglass insulating tape can be fitted to an area where end caps make contact to protect pipe work and reduce heat transfer.
- Care should be taken that end caps are fitted in an orientation that will allow water drainage.
- Sharp edges of cut mesh are to be deburred.
- Removable guards can be made using toggle clips.



Example 1



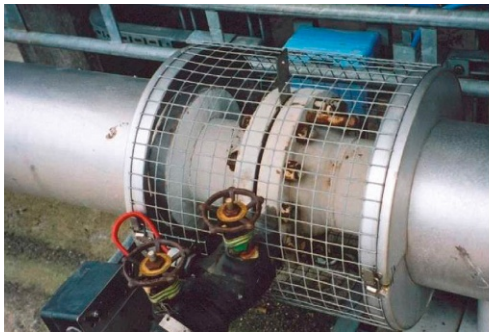
Example 2



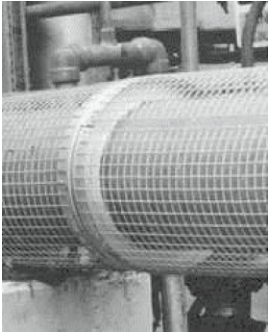
Example 3



Example 4



Example 5



Example 6

Figure H.1 Example photographs of personnel protection guarding installation. (1) Vertical section, (2) reducer, (3) bend, (4) removable boxes for valves, (5) removable box for flange, and (6) use of glass fiber tape.

Appendix I: NDE/NDT techniques

I.1 Visual inspection

Visual inspection is acknowledged as the best method for determining the presence of CUI on carbon manganese and low alloy steels. However, it requires removal of the insulation system and is, therefore, considered to be costly. Normally, the corrosion scale on carbon manganese and low alloy steels involves an increase in volume and is normally 5–10 times greater than the original metal volume loss (see [Figures I.1 and I.2](#)). Absolute quantification of metal loss requires the use of a more elaborate NDE/NDT technique. Although visual inspection can be used for determining the presence of CUI on austenitic stainless steels it is not effective in determining the presence of CI-ESCC.

I.2 Manual ultrasonic thickness measurement through inspection openings

Typically, this method is used to monitor the internal corrosion of carbon manganese and low alloy steel equipment using fixed monitoring points to enable periodic multiple thickness measurements. It can also be used for determining the presence of CUI but is not as effective as measurements conducted from the inside of the vessel, in part due to the limited surface area being measured and the location points (see [Figure I.3](#)). The installation procedures used to make the insulation holes and then make them watertight with caps or covers is expensive and is often limited to accessible areas not always prone to CUI. It is not practical to provide enough inspection locations to get reliable results. The inspection holes cut in the insulation may also compromise the integrity of the insulation and add to the CUI problem if they are not recovered carefully. This technique will not detect CI-ESCC in austenitic stainless steels with any degree of confidence.

I.3 Radiography

I.3.1 Profile radiography

Exposures are made on small sections of pipe and a comparator block is used to calculate the remaining wall thickness of the pipe. The exposure source is usually Iridium 192 (material thickness range of 12–63 mm), and Cobalt 60 (material thickness range of 50–150 mm) used for thicker walled pipes (see [Figure I.4](#)). Cobalt 60 is not used offshore.



Figure I.1 Insulation removal highlighting corrosion product.

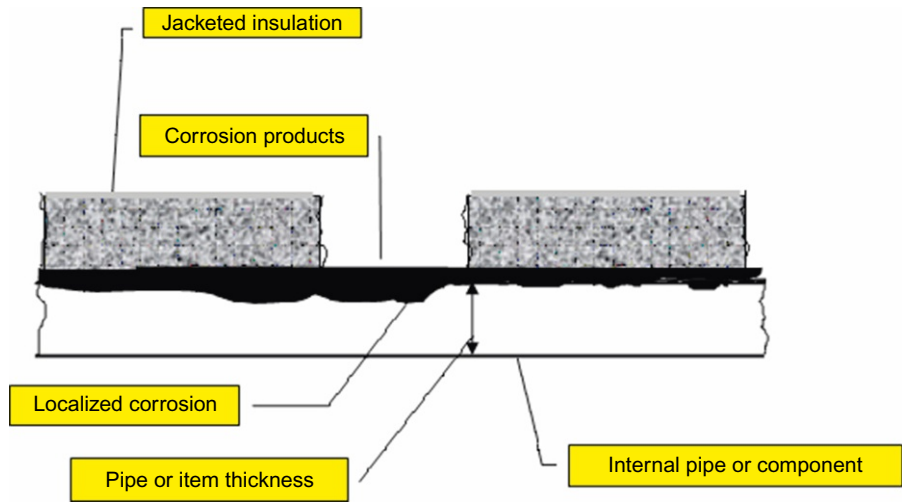


Figure I.2 Visual inspection schematic.

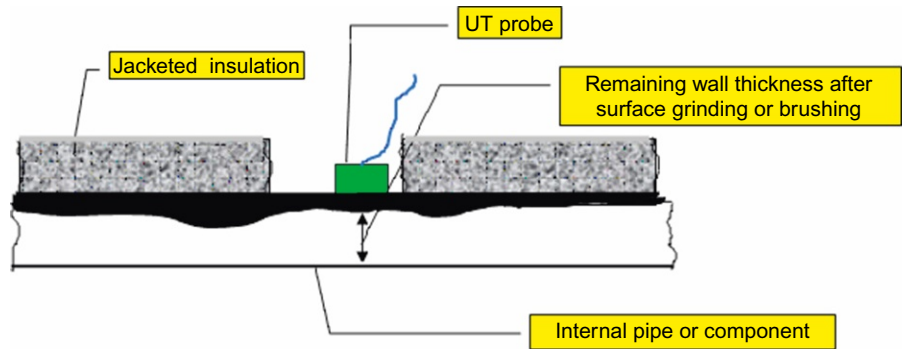


Figure I.3 Ultrasonic thickness schematic.

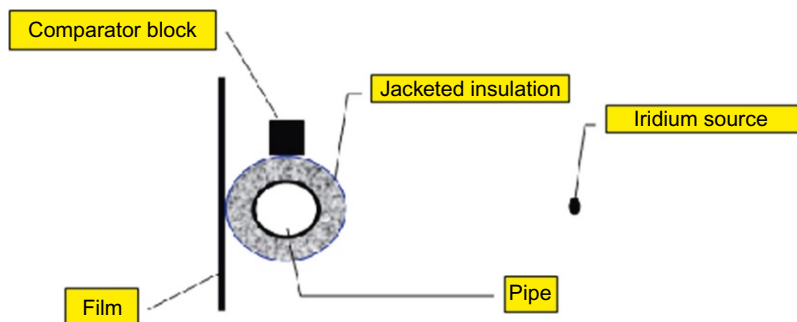


Figure I.4 Profile radiography schematic.

Profile radiography is an effective evaluation method but it becomes technically challenging in piping systems with a nominal diameter greater than 250 mm (10") and only offers limited verification of relatively small areas. Radiation SHE concerns may be overcome by use of SCAR, SafeRad/Digital-computed radiography. Under some radiographic testing conditions, cracking such as SCC can be detected.

This technique does not detect SCC in stainless steels. In addition, radiation safety can be a concern.

1.3.2 Flash radiography

Flash radiography was developed to carry out preventive checks on (insulated) pipelines, vessels, and equipment with diameters up to 1 m. The radiation source is created by discharging a Marx bank (series of capacitors) into a field emission X-ray tube of low impedance. The pulse of radiation is approximately 30 ns. Fast, medical-type film, usually with fluorescent intensifying screens, is often used to produce images from the low radiation flux of the component profile (see Figure I.5).

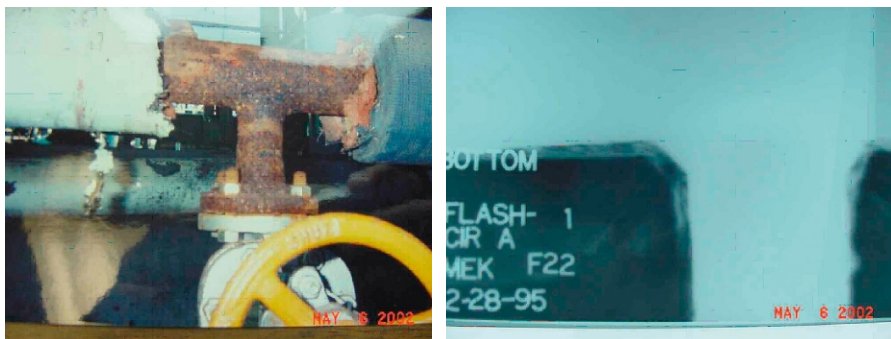


Figure I.5 (a) Profile radiography visual. (b) Profile radiography exposure.

I.4 Real-time radiography

There are two categories of real-time radiography (RTR) devices; one using an X-ray source (Figure I.6) and one using a radioactive source (Figure I.7). Two types of instruments are available, the Lixi Profiler and the Image Scope. The Lixi Profiler is capable of providing wall thickness information. The Image Scope produces an image of the external profile of the surface under insulation (tangential/profile view). The latest RTR equipment includes CMOS and Gamma Scan systems.

Fluoroscopy provides a clear view of the outside diameter of piping, nozzles, or equipment (if small enough) through the insulation, producing a silhouette of the pipe outside diameter (OD) on a TV-type monitor that is viewed during the inspection. No film is used or developed.

X-ray digital fluoroscopy equipment operates at a maximum of 75 KV (i.e., a low level radiation source) but the voltage is adjustable to obtain the clearest image. This allows for safe operation without disruption in operating units or even confined spaces. The radiation penetrates the insulation but not the pipe wall and images the profile of the pipe's outside wall. The radiation is generated electrically so the instrument is perfectly safe when the power is off.

RTR with gamma radiation is a real-time, noncontact density measurement system that provides quantitative wall thickness information using gamma absorption from the isotope Gadolinium 153 (Gd-153). The output of the collimated Gd-153 source is directed to a special scintillator. The scintillator electronics contain the equivalent of a low-level X-ray camera. In turn, the scintillator is coupled to a photomultiplier tube whose electronics are matched to the scintillator output. An output signal is sent to the computer which presents a real-time digital strip chart of the component thickness.

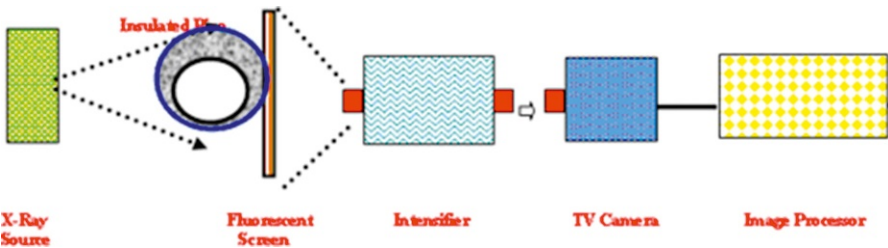


Figure I.6 Real-time X-ray.

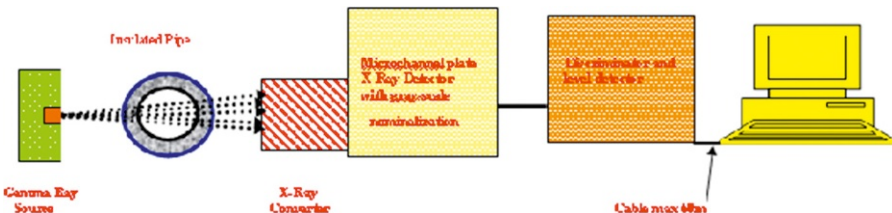


Figure I.7 Real-time gamma ray.

I.5 Guided wave ultrasonic measurements

The guided wave ultrasonic measurement system is a method for inspecting piping or small diameter vessels for internal corrosion as well as CUI. “Guided waves” are ultrasonic waves guided by the geometry of the object in which they are propagating. The waves are transmitted through the wall cross section and inspect the entire volume of the pipe, not just the surface. Therefore, no geometric spreading arises and attenuation is low. The system uses torsional and longitudinal modes. These waves can travel across straight stretches of pipes, bends, supports, and welds. The length of piping that can be inspected is dependent on the piping diameter, orientation, complexity, etc. Long straight lengths of piping are easier to inspect with lengths up to 50m and above achievable.

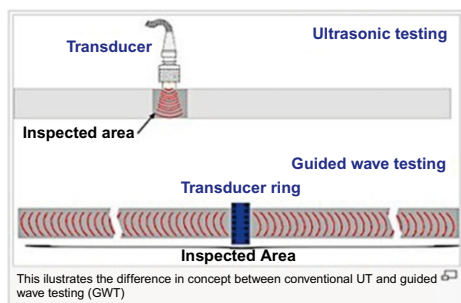
Only a limited amount of coating or insulation has to be removed to place the probe ring on the pipe and because of the outside application of the probe ring the inspection can be carried out while the pipe remains in service. The system has the ability to detect defects in a part of a pipe that is buried or inaccessible, dependent on coating. A probe ring placed around the pipe transmits guided waves through the pipe in either direction of the probe ring. The pulse echo type operation provides information on feature position and approximate size. The interpretation of results is performed with sophisticated analysis aids (see [Figure I.8](#)).

Other examples of guided wave ultrasonic inspection include the Creeping Head Wave Inspection Method (CHIME) and Electromagnetic Transducers (EMATs) both used for inspection of pipe supports.

I.6 Pulsed eddy current

This technique is capable of being used “on-stream” and it measures the average remaining wall thickness of ferro-magnetic material through an insulation layer.

The measurements with the pulsed eddy current technique are based on the phenomena that in materials that are conductive, eddy currents are induced when subjected to a variable magnetic field (see [Figure I.9](#)).



(a)



(b)

Figure I.8 (a) Guided wave. (b) Guided wave piping UT.

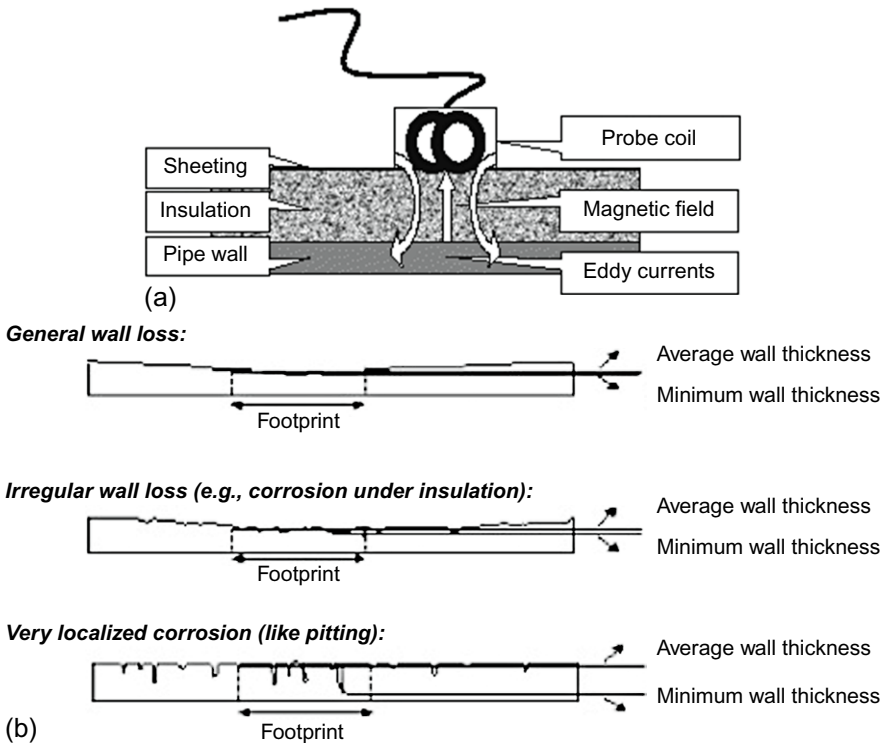


Figure I.9 (a) Pulsed eddy current. (b) Pulsed eddy current thickness measurement limitations.

The strength of the induced magnetic properties depends on the intrinsic magnetic properties of the conductive material, but generally are much stronger. The magnetic field used for the measurements is generated by means of a (transmitter) induction coil system. The coil is placed directly onto the surface of the insulation sheeting at the location to be measured.

During a defined time, a DC-current is sent through the coil causing a stable magnetic field in the pipe or vessel wall. After switching off the current, the magnetic field drops rapidly to zero. This generates eddy currents within the material under examination. The duration of the eddy currents within the enclosed magnetic field is directly related to the thickness of the material. The strength of the magnetic field and the eddy currents has no influence on the duration of the eddy currents (Figure I.10).

The strength and the measurable duration of the eddy currents depend on the strength of the magnetic field as well as the conductivity and permeability of the material. If the strength and duration are measured, the average wall thickness can be calculated. Pulsed eddy current can be used on the flat surfaces of a piping or equipment but corrosion is more likely to occur around nozzle welds, etc., where the eddy current technique cannot be used due to geometric restrictions.

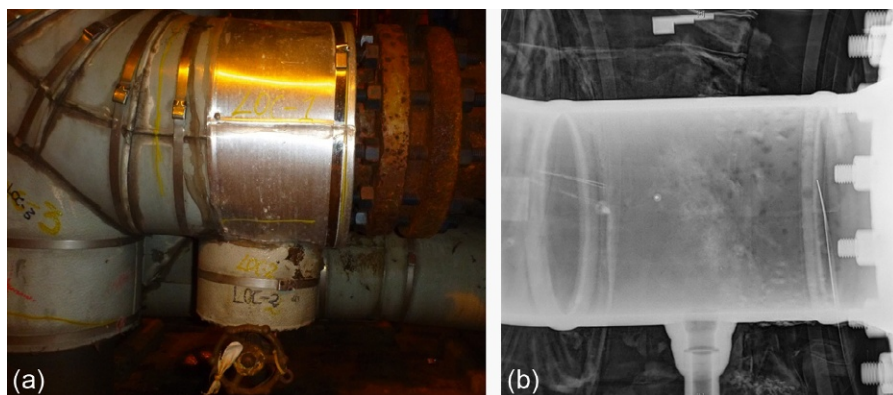


Figure I.10 (a) Digital radiography. (b) Digital radiography infrared view.

I.7 Digital radiography

This system can highlight CUI and provide a measurement of material loss. The measurement sensitivity is dependent on a number of variables. These include exposure conditions, image quality requirements, and productivity. As with conventional radiographic film techniques, digital radiography exhibits a wide range of resolutions, speeds, and throughput capabilities.

The image quality of radiographic devices to achieve different levels of radiographic sensitivity, speed, and throughput, targeted to different applications includes:

- Film Digitization
- Storage Phosphor Computed Radiography (CR)
- Digital Radiography (DR)

Performance characteristics of these systems that can help to determine the right method for application include:

- Resolving capability and penetrameter sensitivity.
- Although radiographers are familiar with penetrameter sensitivity through the use of Image Quality Indicators (IQIs), the resolving capability is not generally measured. A procedure has been developed through HOIS2000 employing EN1435.
- At present, a NDE/NDT standard for measuring resolution does not exist, although there are well established standard methods for evaluating a system's resolving capability.
- Material thickness/loss for any given point.
- Average thickness/loss over any given area ([Table E.2](#)).

I.8 Infrared thermography

This method is not designed to detect CUI, but under the right conditions, infrared thermography can be used to detect damp spots in the insulation, because there is usually a detectable temperature difference between the dry insulation and the wet insulation (see [Figure I.11](#)). Corrosion is a distinct possibility in the areas beneath the wet insulation.

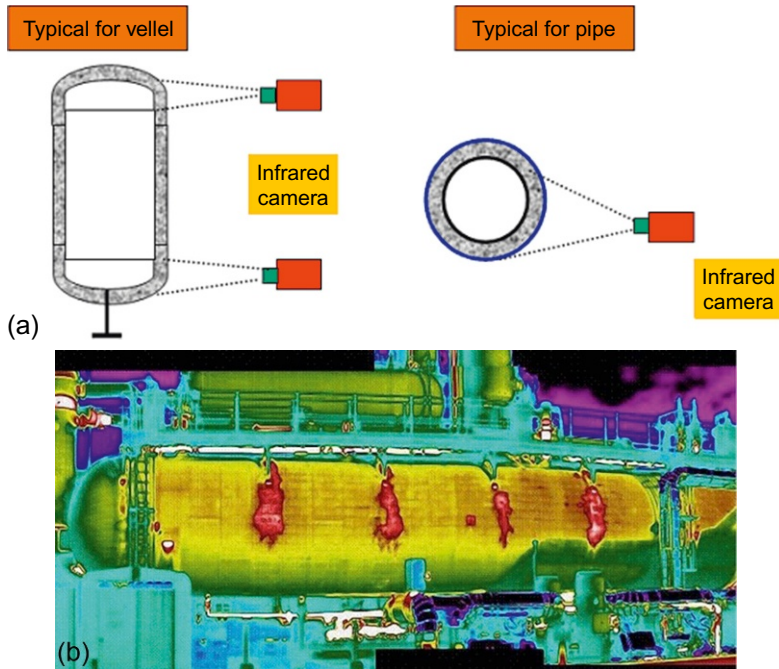


Figure I.11 (a) Infra red thermography system. (b) Infra red example.

Infrared has already been successfully used for a number of years in “Energy Conservation” surveys where defects in insulation manifest themselves as hot or cold spots on the surfaces. These defects can be caused either by bad fits or by subsequent damage caused to insulation due to water ingress. Although wet insulation does not necessarily mean that corrosion is taking place, it is a good indication of where problems may eventually develop and, therefore, such defects should be eliminated as soon as possible.

- It is used for screening
- Provides qualitative assessment of relative temperature at insulation
- CUI indicator is a temperature gradient caused by water (however, it could be other causes of gradients)
- Applications are similar to Neutron Backscatter
- Used for pipe and vessels
- Requires follow-up with a technology to directly assess corrosion
 - e.g., real time radiography (RTR) is a good supplement

I.9 Neutron backscatter

These systems are also not designed to detect CUI directly, but the technique does identify areas of wet insulation on pipes and vessels which may be possible areas of CUI. A radioactive source emits high energy neutrons into the insulation. If there is

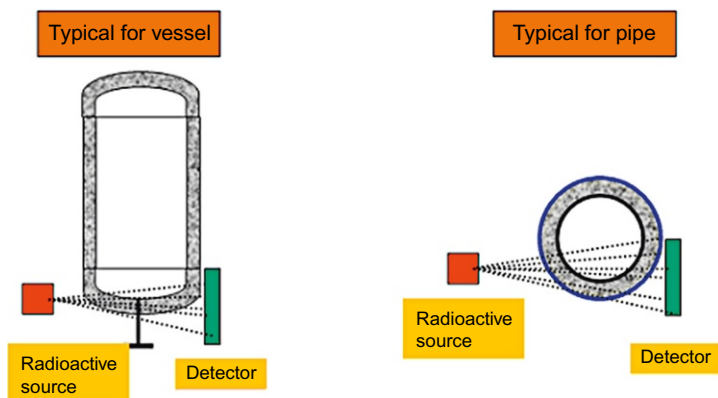


Figure I.12 Neutron backscatter.

moisture in the insulation, the hydrogen nuclei attenuate the energy of the neutrons. The instrument's detector is only sensitive to low energy neutrons. The neutron count displayed is proportional to the amount of water in the insulation. Low counts per time period indicate a low moisture content (see [Figure I.12](#)).

(The detector and source are housed in the same enclosure; in other words, the reflected or back scattered neutrons are detected.)

I.10 Dye penetrant testing

This method is utilized mainly for austenitic stainless steel after the insulation has been removed. Normally, if chlorides are present from chloride containing water or from the insulation material itself, it is possible to initiate SCC in welds or at the bottom of external pitting in material.

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Corrosion-under-insulation (CUI) refers to the external corrosion of piping and vessels that occurs underneath externally clad or jacketed insulation as a result of water penetration. By its very nature, CUI tends to remain undetected until the insulation and cladding/jacketing is removed to allow inspection, or until leaks occur. CUI is a major problem shared by all who operate in the oil and gas (both onshore and offshore), chemical processing and related industries.

EFC Number 55 *Corrosion-Under-Insulation (CUI) Guidelines* was first published in 2008 by the European Federation of Corrosion (EFC) Working Parties WP13 and WP15, with contributions from a number of major European refining, petrochemical and offshore companies. The guidelines reflect a consensus approach to CUI management. They use a high-level, risk-based approach to develop adequate inspection and maintenance strategies, using the currently best practices. Now substantially updated by members of the EFC corrosion community, with significant contributions from companies such as Aramco, Shell, Temati, Sulzer Metco, BP and International Paints, the authors hope that this revised edition will continue to serve the community and act as an important resource for guidance.

Topics covered include: economic considerations; ownership and responsibility; risk-based inspection methodology for corrosion-under-insulation; inspection activities and strategy; nondestructive examination, testing and screening techniques for corrosion-under-insulation; the recommended best practices to mitigate corrosion-under-insulation; design for the prevention of corrosion-under-insulation; substantial appendices in cost-economic evaluation; quality assurance; coatings; types and forms of insulation materials; protection guards and related case studies.

Dr. Stefan Winnik is a materials and corrosion specialist with ExxonMobil Chemical, who now works for SW Materials and Corrosion Ltd.

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