Corrosion Under Insulation and Fireproofing

API RECOMMENDED PRACTICE 583
~~SECOND~~ THIRD EDITION, MARCH 2021

TO BALLOTERS:

This entire document is open for review and ballot. The document contains “red-line” insertions and changes that are the result of the RP 583 task group and industry SMEs work to address scorecard items, add new information and update content from the last edition and volunteered from task group members.

NOTE that significant content changes occurred in section 6.1: Insulation Materials and Thermal Insulative Coatings and section 7.3: Visual Inspection and NDE Techniques. In these sections, most often the old content is shown as deleted even though some portions may be imbedded in the new content.

NOTE: The draft ballot contains a new semi-qualitative likelihood assessment in Annex A, as discussed at the Spring 2024 meeting. During that meeting, a request was made from the task group for the content submitter to explain why this would be a good addition. This explanation is attached to the end of Annex A but only for information purposes and not to be included in the document itself.

In order to properly address comments at the Fall 2024 meeting, please be sure to enter the section numbers under the ballot spot labeled “clause/sub-clause number”; and then under “paragraph/table/figure number” simply indicate which paragraph in the section you are commenting upon.

Please be sure to label comments as “technical” when a substantive change is being made and “editorial” when you are just suggesting some wording improvements. Comments labeled “general” should be those that apply to the multiple sections or the whole document.

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Corrosion Under Insulation and Fireproofing

1 Scope

This recommended practice covers the design, maintenance, inspection, and mitigation practices to address external corrosion under insulation (CUI) and corrosion under fireproofing (CUF). The document discusses the external corrosion of carbon and low alloy steels under insulation and fireproofing and the external chloride stress corrosion cracking (ECSCC) of austenitic and duplex stainless steels under insulation. The document does not cover atmospheric corrosion or corrosion at uninsulated pipe supports but does discuss corrosion at insulated pipe supports.

The purpose of this recommended practice is to:

— help ~~owner/user~~owner-operators understand the complexity of the many CUI/CUF issues;

— provide ~~owner/user~~owner-operators with understanding on the advantages and limitations of the various nondestructive examination methods used to identify CUI and CUF damage;

— provide ~~owner/user~~owner-operators with an approach to risk assessment (i.e. likelihood of failure and consequence of failure) for CUI and CUF damage; and

— provide ~~owner/user~~owner-operators guidance on how to design, install, and maintain insulation systems to avoid CUI and CUF damage.

The practices described in this document apply to pressure vessels, piping, and storage tanks and spheres. The document discusses the factors impacting the damage mechanisms, the guidelines to prevent external corrosion/cracking under insulation, the maintenance practices to avoid damage, the inspection practices to detect/assess damage, and the guidelines for risk assessment of equipment or structural steel subject to CUI and CUF damage.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements and/or recommendations of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration*

API 570, *Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems, 5th Edition*

API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

API Recommended Practice 580, *Risk-Based Inspection*

API Recommended Practice 581, *Risk-Based Inspection Methodology*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*, Fifth Edition

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
ablative coating
A coating that is designed to dissipate heat by oxidative erosion of a heat protection layer (i.e. charring) while protecting the underlying metal substrate.

3.1.2
aerogel
A homogeneous, low-density solid-state material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The resulting material has a porous structure with an average pore, the mean free path of air molecules at standard atmospheric pressure and temperature.

3.1.3
americium 241
Nuclear isotope that emits fast, high-energy neutron radiation; used to detect slow, thermal neutrons generated by collision with hydrogen atoms.

3.1.4
amphoteric
Capable of reacting chemically either as an acid or as a base.

3.1.5
calcium silicate
Insulation that is composed principally of hydrous calcium silicate and usually contains reinforcing fibers.

3.1.6
cellular glass
Insulation that is composed of glass processed to form a rigid foam having a predominately closed-cell structure.

3.1.7
cementitious coating
A coating that contains Portland cement as one of its components and is held onto the applied substrate by a binder; also defined as “binders, aggregates and fibers mixed with water” in API 2218.

3.1.8
chlorosulfonated polyethelene
CSPE
A polymer used for nonmetallic weather jacketing.

~~**3.1.9**~~
~~**cladding**~~
~~See “jacketing.”~~

~~3.1.10~~3.1.9
cobalt 60
Nuclear isotope that emits gamma radiation with far greater penetrating power than iridium 192; used to expose radiographic film, computed radiography (CR) plates, ~~linear diode array (LDA)~~ and digital detector array (DDA) detectors.

~~3.1.11~~3.1.10
cold piping
Piping systems normally operating below the dew point.

~~3.1.12~~3.1.11
comparator block
A steel object such as a steel ball or block used to calculate the geometric unsharpness factor for distortion on a radiograph of a wall pipe. The geometric unsharpness factor is then used to calculate the true thickness of the pipe wall.

~~3.1.13~~3.1.12
composite wrap
A wrapping system composed of multiple nonmetallic fiber/polymer layers to repair corroded piping.

~~3.1.14~~3.1.13
corrosion under fireproofing
CUF
Corrosion of piping, pressure vessels, and structural components resulting from water trapped under fireproofing.

~~3.1.15~~3.1.14
corrosion under insulation
CUI
External corrosion of materials of construction piping, pressure vessels, and structural components resulting from water trapped under insulation; ECSCC of austenitic and duplex stainless steel under insulation is also classified as CUI damage.

~~3.1.16~~3.1.15
~~dead-leg~~deadleg
Section of piping or a piping system where there is no significant flow; examples include: blanked branches, lines with normally closed block valves, lines that have one end blanked, pressurized dummy support legs, stagnant control valve bypass piping, spare pump piping, level bridles, relief valve inlet and outlet header piping, pump trim bypass lines, high point vents, sample points, drains, bleeders, and instrument connections.

~~3.1.17~~3.1.16
deluge system
Defined in NFPA 15, an installation equipped with multiple open nozzles connected to a water supply by means of a deluge valve, which allows water to flow from all nozzles simultaneously. This is similar to a water spray system but does not use directional water spray nozzles to achieve a specific water discharge and distribution. In the refining industry, the term “deluge system” is generally a system without nozzles in which all the water is applied from an open pipe. API 2510 and API 2510A describe such a system at the top of a vessel that allows water to run down the sides in a thin film, frequently using a weir to improve distribution and assist the even flow of water over the protected vessel.

~~3.1.18~~3.1.17
dense concrete fireproofing
Concretes made with Portland cement that can be formed in place or pneumatically sprayed to the required thickness using steel reinforcement.

~~3.1.19~~3.1.18
expanded perlite
A natural volcanic glass similar to obsidian that has been finely ground and subjected to extreme heat, causing the particles to become considerably expanded and porous because of the release of water.

~~3.1.20~~3.1.19

external chloride stress corrosion cracking

ECSCC

Surface initiated cracking in austenitic and duplex stainless steels and some nickel base alloys under the combined action of tensile stress, temperature, and an aqueous chloride environment.

~~3.1.21~~3.1.20

fiberglass (glass wool)

A synthetic vitreous fiber insulation made by melting predominantly silica sand and other inorganic materials, and then physically forming the melt into fibers.

~~3.1.22~~3.1.21

fireproofing

A systematic process, including design, material selection, and the application of materials, that provide a degree of fire resistance for protected substrates and assemblies.

~~3.1.23~~3.1.22

fluoroscopy

Real-time X-ray system based on the principle of fluorescing screens.

~~3.1.24~~3.1.23

gadolinium 153

Nuclear isotope that emits gamma radiation.

~~3.1.25~~3.1.24

gamma radiation

Photons or packets of energy emitted from certain nuclear isotopes such as iridium 192 or cobalt 60.

~~3.1.26~~3.1.25

hydrophobic

Having little affinity for water, nonwettable.

~~3.1.27~~3.1.26

ice lens

A localized zone of ice accumulation.

~~3.1.28~~3.1.27

ice-to-air interface

Transition points on cold service insulation systems operating below the freezing point that forms an ice-to-air interface; depending on time of year (such as summer and winter months), the size of the ice at these locations changes by continually freezing and thawing.

~~3.1.29~~3.1.28

insulating/insulative coating

Composite insulators with a thickness of 20–200 mils and operating temperature ranges 40–500 °F used for personnel protection, energy and thermal conservation, and preventing corrosion under insulation.

3.1.29 ~~3.1.29.5~~

insulation drying wrap

A perforated and dimpled wrap meant to go under the jacketing and over the insulation with the intention of achieving a breathable/self-drying insulation system.

3.1.30

intumescent coating
A fire-retardant coating that, when heated, produces nonflammable gases that are trapped by the film, converting them to a foam and thereby insulating the substrate.

3.1.31
iridium 192
Nuclear isotope that emits gamma radiation; used to expose radiographic film computed radiography (CR) plates, ~~linear diode array (LDA)~~ and digital detector array (DDA) detectors.

3.1.32
jacketing
The protective covering that is applied over insulation~~;~~.

NOTE ~~a~~Also referred to as “sheathing” or “cladding.”

~~3.1.33~~
~~lagging~~
~~Another name for insulation.~~
3.1.33 ~~3.1.32.5~~
leachate sleeve/barrier
A membrane to create an impermeable barrier between the insulation and the pipe to separate the wet insulation from the pipe.

3.1.34
lightweight cementitious fireproofing
A sprayed or troweled coating formulated from Portland cement and lightweight aggregate, such as vermiculite, perlite, and diatomite in place of the usual sand and stone.

3.1.35
lightweight concrete fireproofing
A concrete that uses very light aggregate, such as vermiculite or perlite (instead of gravel), with cements that are resistant to high temperatures.

~~linear diode array~~
~~LDA~~
~~A linear diode array is used for digitizing radiographic images. The LDA system consists of an array of photodiode modules. The diodes are laminated with a scintillation screen to create X-ray sensitive diodes.~~

3.1.36
mastic
A pasty material used as a protective coating or cement.

3.1.37
microporous flexible thin blanket insulation
Material in the form of compacted powder with an average interconnecting pore size comparable to or below the mean free path of air molecules at standard atmospheric temperature and pressure. Microporous insulation may contain fibers to add integral strength and may contain opacifiers to reduce the amount of radiant heat transmitted.

3.1.38
mineral fiber

Synthetic vitreous fibers manufactured from rock, slag, or glass.

3.1.39
mineral wool
A synthetic vitreous fiber insulation made by melting predominantly igneous rock, and/or furnace slag, and other inorganic materials and then physically forming the melt into fibers. To form an insulation product, there are often other materials applied to the mineral wool such as binders, oils, etc.

3.1.40
neutron backscatter ~~testing~~examination method
A nondestructive test method that uses high-energy (fast) neutrons to detect the presence of hydrogen atoms.

3.1.41 ~~3.1.40.5~~
non-contact insulation system
An insulation system that has an intentional gap between insulation and the pipe to keep the insulation off the pipe along with minimizing the risk of oxygen concentration cells formation at pipe-insulation interface.

~~3.1.41~~3.1.42
perlite
Natural volcanic material that is heat expanded to a form used for lightweight concrete aggregate and fireproofing.

~~3.1.42~~3.1.43
photolysis
Chemical decomposition of polystyrene foam caused by light or other electromagnetic radiation.

~~3.1.43~~3.1.44
polyisocyanurate foam
A closed-cell, thermoset, plastic foam formed by combining isocyanurate, polyol, surfactants, catalysts, and blowing agents.

~~PT~~
~~Liquid penetrant examination method.~~

~~3.1.44~~3.1.45
pulsed eddy current examination method
PEC
An eddy current examination method that uses a stepped or pulsed input signal instead of a continuous signal used by conventional eddy current techniques. This technique has a greater penetration depth and is less sensitive to lift-off than conventional eddy current techniques.

~~3.1.45~~3.1.46
real-time radiographic examination method
RTR
A nondestructive test method whereby an image is produced electronically rather than on film so that very little lag time occurs between the item being exposed to radiation and the resulting image.

~~3.1.46~~3.1.47
reliability-centered maintenance
A process used to determine the maintenance requirements of any physical asset in its operating context.

~~**3.1.47**~~
~~**sheathing**~~
~~See “jacketing.”~~

3.1.48
silica aerogel flexible blanket
A flexible insulation containing a composite of aerogel, fibrous carrying media, or reinforcements, or a combination thereof.

3.1.49
structural steel
Steel shaped for use in construction including I-beams, vessel skirts, and saddles for exchangers and other horizontal vessels.

3.1.50
subliming compound
A coating where the active ingredient absorbs heat as it changes directly from a solid to a gas phase; as in the case of ablative coatings, intumescents are incorporated to provide an additional insulating layer.

3.1.51
transition points
Protrusions through the insulation system (e.g. vents, drains, supports, nozzles, instrument connections, etc.) on carbon steel piping and equipment operating at below ambient or cold service temperatures (includes those operating below 10 °F).

3.1.52
vermiculite
A group of minerals characterized by their ability to expand into long, wormlike strands when heated; this expansion process is called “exfoliation.”

3.1.53
water resistant
Resistant but not impervious to penetration by water.

3.1.54
X-ray
Photons or packets of energy emitted from the cathode ray tube of an X-ray unit when the cathode is bombarded with electrons.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

AWT	average wall thickness
CR	computed radiography
CSPE	chlorosulfonated polyethylene
CUF	corrosion under fireproofing
CUI	corrosion under insulation

DDA	digital detector array
ECSCC	external chloride stress corrosion cracking
EPS	expanded polystyrene
ET	eddy current examination method
FFS	fitness-for-service
GRP	glass-reinforced plastic
GWT	guided wave testing
ID	inside diameter
IGSCC	intergranular stress corrosion cracking
ILI	in-line inspection
IR	infrared imaging
MDI	moisture detection imaging
MOC	management of change
NPS	nominal pipe size
OD	outside diameter
PEC	pulsed eddy current examination method
PIR	polyisocyanurate
PT	liquid penetrant examination method
PSP	photostimulable phosphor
PVC	polyvinyl chloride
RBI	risk-based inspection
RTR	real-time radiographic examination method
SCC	stress corrosion cracking
SEC	surface eddy current examination method
SECA	surface eddy current array examination method
TSA	thermal spray aluminum

UV	ultraviolet
XPS	extruded polystyrene

4 Introduction to the Causes of Damage

4.1 General

Thermal insulation is used on the exterior of equipment and piping for a variety of reasons including:

- heat conservation [usually >200 °F (93 °C)];
- cold conservation (refrigeration systems) [usually <40 °F (4 °C)];
- personnel protection [usually >140 °F (60 °C)];
- freeze protection/heat tracing;
- condensation control;
- acoustic (noise) reduction;
- fire protection;
- process control.

By contrast, fireproofing is used on structural steel solely to minimize, for a period of time, the impact of temperatures generated during a fire on structural supports for pressure vessels (i.e. skirts) or piping (I-beams). Despite their different applications, corrosion under insulation (CUI) and corrosion under fireproofing (CUF) have similar degradation mechanisms in that corrosion of the steel substrate may occur in certain situations when water accumulates at the underlying steel surface. In stainless steels, CUI damage takes the form of environmental cracking.

In addition to this document, a discussion of the causes of CUI and CUF damage, inspection methods for detecting damage, and other CUI- and CUF-related topics can be found in API 571, ASTM STP 880, and IMMM EFC 55.

4.2 CUI in Carbon and Low Alloy Steels

4.2.1 General

CUI is defined as the external corrosion or cracking of piping and vessels that occurs when water gets trapped beneath insulation. CUI damage takes the form of localized external corrosion in carbon and low alloy steels. The factors that affect the amount of CUI damage under insulation include:

- duration of the exposure to moisture;
- cyclical operation in and out of CUI range and/or intermittent operation;
- frequency of the exposure to moisture;
- corrosivity of the aqueous environment;

- condition of protective barriers (e.g. coating and jacketing);
- equipment design issues;
- service temperature—cold can sweat/stay wet, hot may drive off moisture;
- insulation type;
- condition of weather barriers and caulking;
- type of climate;
- site maintenance practices;
- leaking steam-tracing systems;
- proximity to humidity-causing equipment, such as cooling towers;
- proximity to saltwater; and
- high industrial area acidic rainwater.

CUI damage is characterized by either general metal wastage or pitting due to the localized breakdown of passivity. It is a form of oxygen corrosion and occurs on carbon and low alloy steel when exposed to moisture and oxygen. Damage occurs when water is absorbed by or collected beneath the insulation due to breaks in the insulation or jacketing (cladding) and remains unable to evaporate from the insulation; therefore, the moisture contacts and stays on the underlying exposed steel. Theoretically, this occurs at metal temperatures between 32 °F (0 °C) and 212 °F (100 °C). Water may come from numerous sources such as rainwater, a deluge system, spillage from process operations, leaking steam tracing, or condensation on the metal surface in humid environments. Exposure to water can and will damage non-immersion grade paint. Also, holidays in the paint allow for contact with electrolytic and can undermine the paint. While painting is a best practice, the metal will still be prone to CUI when insulated.

When determining CUI susceptibility, a much broader operating temperature range should be considered, typically from 10 °F to 350 °F (–12 °C to 177 °C) because of fluctuations in operating temperature, ineffective insulation maintenance, type of insulation, insulation or coating system damage, temperature gradients within the equipment considered (long pipe runs, fractionation columns, heat exchangers, etc.), and various operating modes. Contaminants in the insulation, such as chlorides and sulfides, may contribute to the corrosivity of the environment.

In some instances, these differences arise because users have reported actual metal temperature for CUI incidents, other users have reported actual process temperature in reports of CUI damage, and some have introduced a margin of safety. This has led to an expanding of the range where CUI damage may occur. The temperature range that CUI damage is most severe depends on many different factors but in many areas has been found to be at metal temperatures between 170 °F and 230 °F (77 °C and 110 °C) where corrosion reaction kinetics are the highest.

All operating conditions should be considered, including the out-of-service state, for equipment that is offline at ambient temperatures for significant periods of time. Equipment that cycles in and out of the CUI range during regeneration cycles or is frequently out-of-service at ambient conditions, can experience aggressive CUI damage even though when in normal operation, it is outside the CUI temperature range.

4.2.2 CUI Damage Below 32 °F (0 °C) and Above 212 °F (100 °C)

The temperature range quoted for CUI can vary from one document to another and may list temperatures where liquid water would not be predicted [i.e. below 32 °F (0 °C) and above 212 °F (100 °C)]. This is because users sometimes report the temperature where damage occurred based on the process operating temperature rather than the actual metal surface temperature. The key factor for CUI damage to occur is that a corrosive aqueous layer be present on the insulated metal surface during any operating period or during downtime.

One possible situation is where water breaches the insulation contacting ~~coming in contact with~~ the metal surface at temperatures between 212 °F and 350 °F (100 °C and 177 °C). CUI damage could be occurring as the result of continual flashing of water at the hot metal surface that can concentrate chlorides on the metal surface. Even at surface metal temperatures up to 600 °F (316 °C), CUI could occur during operation if water reaches the metal surface during a shutdown period and flashes off during start-up. Another instance where CUI can occur is where deposits in a ~~dead-leg~~deadleg reduce the surface metal temperature sufficiently to allow CUI to take place. Other examples include nozzles, platform support protrusions, etc. CUI damage may also occur in equipment operating at process temperatures below 32 °F (0 °C) as the result of cyclic exposure conditions above 32 °F (0 °C) or frequent unit shutdown. It is more important to determine whether water is breaching the insulation system rather than dwelling on what the exact temperature of the insulated metal surface is during normal operation. It should be noted that it is very difficult for insulation jacketing/cladding systems to be leak tight. Section 7 and API 571 provide information on CUI inspection practices.

4.2.3 Intergranular Stress Corrosion Cracking (IGSCC) in Carbon Steel

Some Canadian owner-operators have experienced IGSCC of carbon steel piping and equipment beneath insulation. The common characteristics of this cracking of carbon steel are:

a) Uncoated, non-~~PWHT~~post-weld heat treated carbon steel,

b) Steel in contact with wet mineral wool of vintage 2003-2013

c) Operating between 160°F (70°C) and 375°F (190°C)

The majority of the cracks were found along the lower half of the pipe or equipment, where moisture collects, and particularly around high-residual stress areas, i.e. induction bends, formed fittings, fillet welds on pipe shoes, longitudinal seams and girth welds.

Research into the mechanism of IGSCC is ongoing, with the aim of gaining a comprehensive understanding. Laboratory tests replicating IGSCC suggest that the cracking reagent originates from the mineral wool leachate. Cracking has not been experienced in the field with other insulation materials apart from wet mineral wool. Although lab tests will be performed to assess whether leachates extracted from other unsulation materials generate cracking of carbon steel. The current theory is that at operating temperature, insulation binders and other insulation system components thermally degrade and release the cracking reagent(s).

For assets identified as potentially susceptible to IGSCC, inspection activities could include a survey for wet insulation (e.g., visual inspection, neutron backscatter, and/or infrared camera) and/or inspection for cracking. Surface eddy current is one common examination method successfully used to detect and size IGSCC (see section 7).

Their practice to prevent IGSCC of existing installations has been to install a leachate barrier to separate the mineral wool insulation from the steel pipe in case it gets wet. Other options include applying a suitable protective coating (e.g. thermal spray aluminum (TSA), high temperature epoxy) and/or completely replacing the mineral wool with alternate insulation systems. Any protective coating should be assessed to ensure it is resistant to the leachate, up to pH 9, and operating conditions for long-term service.

4.3 CUI in Austenitic and Duplex Stainless Steels

CUI damage in austenitic and duplex stainless steels is a form of external chloride stress corrosion cracking (ECSCC). As with all forms of stress corrosion cracking (SCC), cracking occurs when a susceptible metallurgy is exposed to the combined action of a corrosive environment and an applied/residual tensile stress. Susceptible materials include Type 300 series austenitic stainless steels. Duplex stainless steels, although more resistant than austenitic stainless steels, are not immune. A corrosive environment occurs when chlorides concentrate under the insulation at the surface of the austenitic stainless or duplex steel when the insulation becomes wet. Residual cold work from fabrication or residual welding stresses provides the tensile stresses necessary promote cracking.

Most CUI damage in austenitic stainless steels occurs at metal temperatures between 140 °F and 350 °F (60 °C and 177 °C), although exceptions have been reported at lower temperatures. Below 120 °F (49 °C), it is difficult to concentrate significant amounts of chlorides, whereas above 350 °F (177 °C), water is not normally present, and CUI damage is infrequent. It should be noted that even austenitic stainless steel piping that normally operates above 500 °F (260 °C) can suffer severe ECSCC during start-up after insulation gets soaked from deluge system testing, from fire water, or from rain during downtime or the leachable chlorides from insulation. Typically, CUI damage in austenitic and duplex stainless steels goes unnoticed until insulation is removed, or a leak occurs.

CUI damage in duplex stainless steels occurs at higher temperatures than observed for austenitic stainless steels. Figure 1 shows the results of SCC tests conducted on austenitic and duplex stainless steels. As can be seen from these results, SCC of duplex stainless steels does not occur until about 285 °F (140 °C) at very high chloride concentration levels. In general, there have been few reported cases of cracking in the industry, but those that have been reported were under severe conditions where SCC could be predicted. Some of the failures reported have been on offshore facilities and were attributed to ECSCC on relatively hot equipment. API 938-C discusses the use of duplex stainless steels in the refining industry.

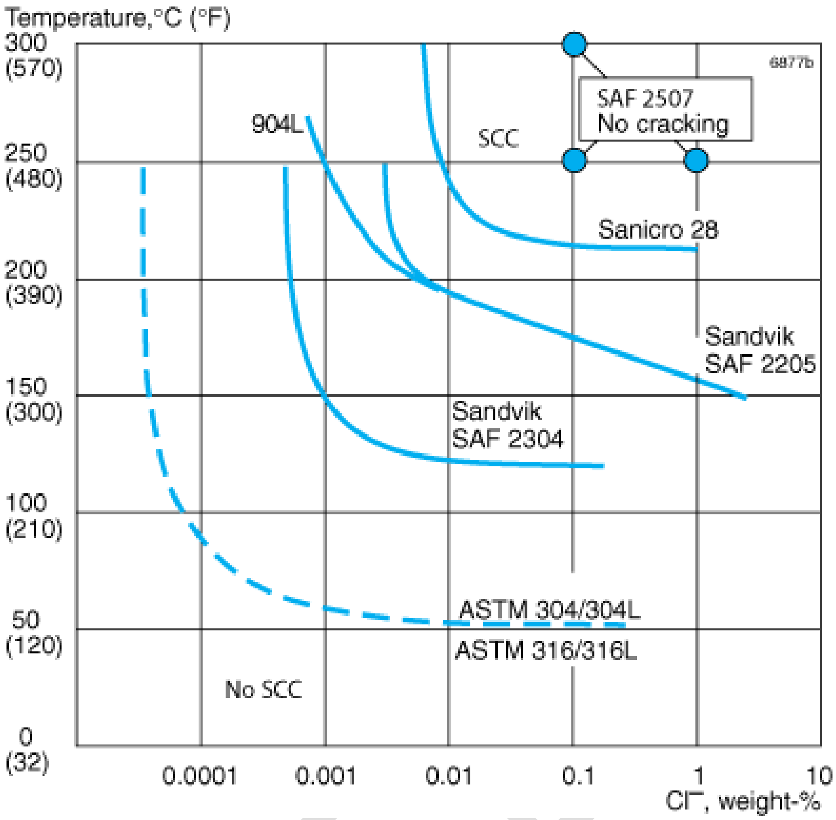


Figure 1—SCC Tendency of Austenitic and Duplex Alloys ~~[1]~~

4.4 CUF in Carbon and Low Alloy Steels

Fireproofing is used on structural steel, supporting piping, and pressure vessels in process units (i.e. I-beams and skirts) to minimize the escalation of a fire that would occur with the failure of structural steel supporting piping and pressure vessels. Fireproofing is designed to extend the time it takes for structural steel from reaching 1000 °F (540 °C) and allow more time for site personnel to control the fire. At 1000 °F (540 °C), the tensile strength of carbon steel is reduced to roughly 50 % of its room temperature value and impacts the load-bearing ability of these components. The premature failure of these structural supports could add significant fuel to the fire as the equipment or piping collapse can result in loss of containment of other flammable fluids.

~~[1] https://www.materials.sandvik/en/materials-center/material-datasheets/tube-and-pipe-seamless/sandvik-saf-2507.~~

Localized CUF damage tends to occur in highly industrialized areas with high SO_2 levels in the atmosphere or marine environments when operating, either continuously or intermittently, in the temperature range of 25 °F to 250 °F (–4 °C to 121 °C). When high-chloride-containing water is used to mix concrete fireproofing, metal loss can be quite severe. Some older installations involved solvent reduction (i.e. thinning) of the coating material with chlorinated solvents when the coating was applied during hot, dry weather. Some of the chlorinated solvent can remain in the dried film and produce hydrochloric acid with aging. In addition, prolonged exposure to heat at less than the design temperature may allow for the slow release of acid and subsequent corrosion. This is because the intumescent response to heat is acid activated and may not act instantaneously at the design temperature in response to a fire, typically 392 °F to 482 °F (200 °C to 250 °C).

The corrosion products resulting from CUF can promote cracking or spalling of the fireproofing. This occurs because the corrosion products formed [i.e. essentially iron oxides (Fe_2O_3 and Fe_3O_4)] have a density that is roughly 33 % lower than carbon steel. As a result, the corroded metal occupies a greater volume than the original uncorroded steel, exerting tensile stresses on the fireproofing. Cracking of the fireproofing occurs when sufficient corrosion product builds up between the fireproofing and the underlying steel. Cracking and staining of the fireproofing provide visual evidence that corrosion is occurring on the underlying steel.

4.5 CUI on Aluminum Piping

Aluminum piping is commonly used in processes that perform liquefaction of various gases. Because of the nature of the process, extremely cold temperatures occur during operation. Condensation is common on the surface of piping with a differential surface temperature as compared to ambient.

In most cases, the aluminum piping exposed to cold temperature is insulated. At points of breach in the insulation, moisture in the atmosphere condenses on cold pipe surfaces. Moisture on aluminum pipe in the presence of differential materials such as carbon steel, stainless steel, or copper can initiate galvanic corrosion. Additionally, in marine environments, chlorides can initiate pitting and cracking of aluminum alloys.

Insulation of complex piping geometry results in large areas of piping encapsulated within insulation boxes. Visual inspection is not possible until insulation boxes are emptied. Wet areas within these encapsulation boxes create a high probability of degradation due to corrosion.

Piping support equipment can cause accelerated corrosion points. An example of this accelerated corrosion is stainless steel “U” bolts used to secure piping to structures or support ancillary items such as insulation.

Ice forming on the pipe surface also creates a wet area and hinders visual inspection. Cyclic service creates additional wet conditions during ice thaw.

Saltwater ingress associated with residual stress and crevice corrosion can cause failure of aluminum piping by SCC.

5 Areas Susceptible to Damage

5.1 General

Under the right temperature conditions, CUI or CUF damage can occur at any location that is insulated or fireproofed. CUI and CUF are somewhat insidious in that regard. It is not uncommon to find CUI/CUF damage in locations remote from the more predictable and susceptible locations. However, there are some areas within facilities that experience has shown have a higher susceptibility for damage. In general, areas with severe CUF damage are easier to identify visually than CUI damage because of cracks and staining of the fireproofing. Certain areas and types of equipment have a higher susceptibility for CUI damage.

5.2 General Areas of Damage

There are a number of locations in oil or chemical processing facilities where CUI damage or CUF has a higher likelihood. Areas common to all equipment types are listed in Table 1.

Table 1—Locations for CUI Throughout Process Facilities

Equipment Type	Potential Locations
General areas	Areas downwind of cooling towers exposed to cooling tower mist
	Areas of protrusions (i.e. transition points) through the jacketing at manways, nozzles, vessel/piping supports, and other components
	Areas of protrusions through insulation for equipment/piping operating at or below ambient, or in cold service
	Areas with insulation plugs, especially where they have been improperly installed, damaged, or misplaced
	Areas where insulation jacketing is damaged or missing
	Areas where the insulation jacketing seams are oriented so that water can freely enter the jacketing
	Areas where caulking is missing or hardened on insulation jacketing
	Areas where the jacketing system is bulged or stained
	Areas where banding on jacketing is missing
	Areas where thickness monitoring plugs are missing
	Areas where vibration has caused damage to the insulation jacketing
	Areas exposed to steam vents
	Areas exposed to process spills, the ingress of moisture, or acid vapors
	Areas exposed to deluge systems
	Areas insulated solely for personnel protection
	Areas under the insulation with deteriorated coatings or wraps
	Areas with leaking steam tracing
	Pipe and flanges on pressure safety valves
	Systems that operate intermittently above 250 °F (121 °C)
	Systems operating below the atmospheric dew point
	Systems that cycle through the atmospheric dew point

	Ice-to-air interfaces on insulated systems that continually freeze and thaw
	~~Dead-legs~~Deadlegs

Table 2—Locations for CUI/CUF on Vessels

Equipment Type	Potential Locations
Pressure vessels	Insulation support rings below damaged or inadequately caulked insulation on vertical heads and bottom zones
	Stiffening rings on insulated vessels/columns in vacuum service
	Insulated zone at skirt weld
	Insulated leg supports on small vessels
	Ladder and platform attachments
	Termination of insulation at nozzles and saddles
	Fireproofed skirts (CUF)
	Anchor bolts (CUF)
	Bottom of horizontal vessels (i.e. lower third to half of vessel)
	Irregular shapes that result in complex insulation installations (e.g. davit arm supports, lifting lugs, body flanges, etc.)

All equipment is shut down at some time or other. The length of time and the frequency of the downtime spent at ambient temperature may well contribute to the amount of CUI that occurs in the equipment. An example of damage to the jacketing that would allow water to saturate the insulation is similar to what is shown in Figure 2.

5.3 Pressure Vessels

In addition to the areas listed in Table 1, there are other areas in vessels, columns, drums, and heat exchangers where CUI may have a higher likelihood. These are shown in Table 2.

5.4 Piping

5.4.1 General

In addition to the areas listed in Table 1, there are other areas in piping where CUI may have a higher likelihood, and this includes process piping, refrigerated piping, piping at or below grade, pipe supports, or where there is a moisture leak spot. Figure 3 shows a CUI failure of piping in a compressor recycle line. Experience has shown that people will consider cold piping that operates outside of the given materials CUI range to be not susceptible to CUI and later find that nozzles, supports, insulation terminations are warmer, offering a transition into the CUI range.

Susceptible locations for CUI and CUF in piping are listed in Table 3.

Table 3—Susceptible Locations for CUI and CUF in Piping

Equipment Type	Potential Locations
Piping	~~Dead-legs~~Deadlegs, vents, and drains
	Pipe hangers and supports
	Valves and fittings
	Bolted on pipe shoes
	Insulation plugs, especially where they have been improperly installed, damaged, or misplaced
	Steam-tracing/electric-tracing tubing penetrations
	Termination of insulation at flanges and other piping components
	Areas where smaller branch connections intersect larger diameter lines
	Low points in piping, such as bottom of vertical runs
	Close proximity to water (e.g. wharf) and/or ground (e.g. increased absorption)
	Wet due to flooding or submerging into water
	Damage due to foot traffic

5.4.2 Cold Piping

In this document, cold piping is considered to be piping carrying liquid or gases that cool the piping to temperatures below the dew point. Cold piping is prone to corrosion because of condensation with CUI often occurring in locations remote from the predictable and susceptible locations. The condensation present can freeze in cases where the temperature of the outside surface of the piping decreases below freezing. In many cases, such as ammonia terminals, piping temperatures can swing from ambient to –30 °F (–34 °C) during periods when ammonia is flowing in the piping. This temperature swing leads to continuous freezing and thawing, and results in wet conditions that increase the piping system susceptibility to CUI damage. Additionally, other equipment and components such as tanks, pressure vessels, pipe supports, and flanges connected by this piping may be affected by the runoff of melting ice or condensed water.

Ice layers can form on piping operating at temperatures below freezing and can obscure the view of external surface damage due to a continuous wet environment. In many cases, piping used for these cold temperature applications is insulated. Frequent chilling and condensation accelerate corrosion at points where the insulation system is breached, which exposes the surface of the piping to the atmosphere (i.e. ice-to-air interfaces). Water ingress, due to poorly sealed insulation jacketing, can result in ice buildup causing swelling of the insulation and create a larger area of damage to the insulation system. This repeated condition creates more and more exposure and susceptibility to corrosion.

Figure 2—Jacketed Piping with Missing Insulation Plug (top photo) Allowing Water Ingress and

Subsequently Corrosion on Piping Elbow (bottom photo)

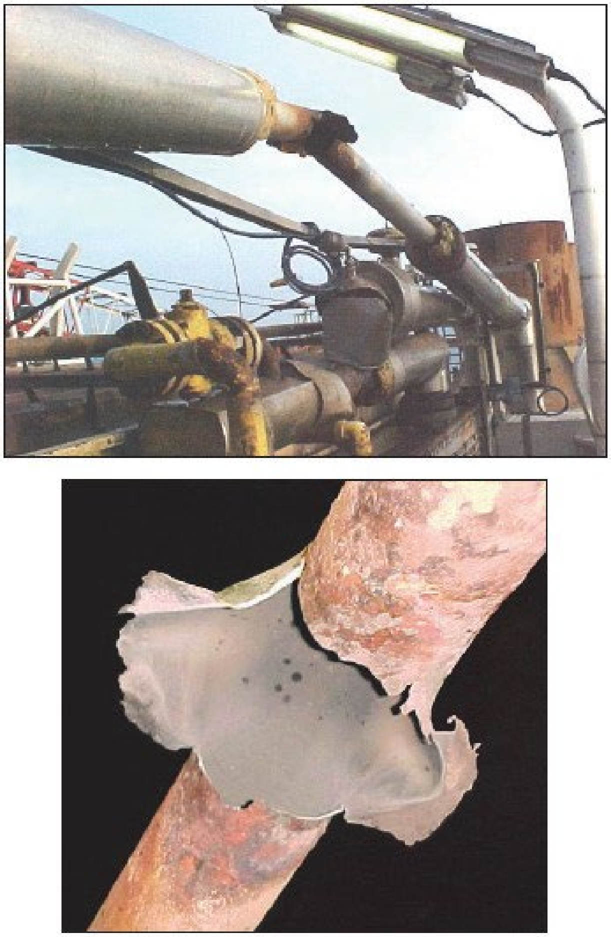


Figure 3—CUI Failure of 4 in. Gas Compressor Recycle Line

Some common areas where breaches in insulation may occur and promote condensation are shown in Table 4.

Table 4—Susceptible Locations for CUI/CUF in Piping Operating Below the Dew Point

Equipment Type	Susceptible Locations
Cold piping	Pipe supports
	Insulation termination areas such as pipe-to-flange locations
	Flanges with stud bolts where insulation bonnets are installed but not sealed
	Piping below flood grade where rising water penetrates the insulation jacketing causing ice lens with swelling that causes jacketing failure
	High foot traffic areas where insulation is degraded by contact with human traffic

	Areas on the insulation jacket showing signs of continual surface condensation or mold
	Holes or cuts in the insulation vapor retarder or jacket
	Ice-to-air interfaces

5.4.3 Pipe Supports

The accumulation of water can occur at locations remote from the point of intrusion, especially in services where the surface temperature does not cause the water to evaporate. For example, this can occur on a horizontal line in the low point of a span between pipe supports, where the insulation is missing at the supports, or there is water ingress due to lack of sealing.

Yet evaporated water may also travel through the insulated system and condense in areas with a lower surface temperature.

There are many process units that operate at temperatures as low as –320 °F (–196 °C) in chemical plants, refineries, and LNG facilities. In addition to supporting the piping and permitting limited movement, pipe supports in these applications need to be insulated to increase the efficiency of the piping system by not allowing heat to transfer into the process fluids contained in the piping.

Whenever possible, pipe supports should be located outside the insulation system.

5.5 Tankage and Spheres

Susceptible locations for CUI and CUF damage in various equipment types are listed in Table 5. This includes insulated tanks and spheres in both hot and cold service. Examples of CUI and CUF damage in tanks and spheres are shown in Figure 4 and Figure 5.

Table 5—Locations for CUI/CUF in Tanks and Spheres

Equipment Type	Susceptible Locations
Tanks/spheres	Area above chime
	Stairway tread attachments
	Insulation support rings
	Fireproofed legs on spheres (CUF)
	Insulation penetrations such as nozzles, brackets, etc. on shell and roof

5.6 Heat-traced Systems

Heat-traced systems are used to protect pipes from freezing or to maintain process temperatures for piping that transport substances that solidify or lose viscosity at ambient temperatures. Heat-traced systems are divided between electric- and steam-traced systems. From a design perspective, electric-traced systems with chloride-free [i.e. non-polyvinyl chloride (PVC)] electrical insulation would be the preferred choice to minimize CUI damage in insulated systems. Although this may be the preferred choice to minimize CUI damage, in reality, the majority of systems in use today are steam-traced systems.

Figure 4—CUI at an Insulation Support Ring

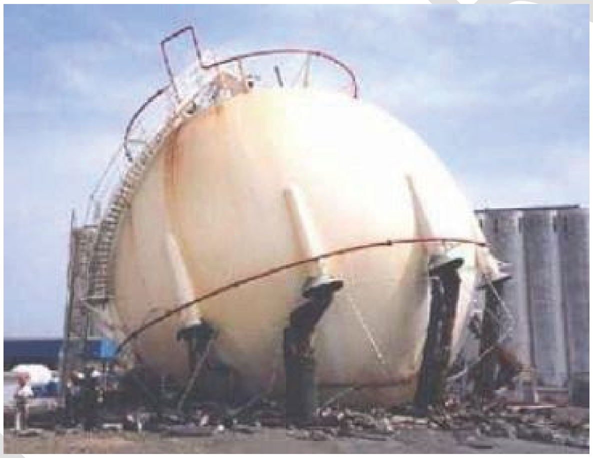


Figure 5—Failure of Sphere Legs Due to CUF

When steam tracing fails, it defeats all CUI barriers. These systems often fail at coupling joints under the insulation. When steam tracing fails under insulation, it introduces moisture, strips away protective coatings, and raises the metal surface temperature within the CUI temperature regime. In addition, the same conditions can potentially cause ECSCC on austenitic stainless steel pipe and instrument tubing under the insulation. It is good practice to locate heat trace couplings outside the weather jacketing. For insulated equipment that has been idle for an extended period of time, consideration should be given to stripping old insulation for inspection and mitigation before returning it to service.

5.7 Shutdown/Mothballing

Carbon steel and low alloy e~~E~~quipment or piping systems that are or will be shut down for extensive periods or mothballed ~~also~~ have higher ~~susceptibility~~ potential for CUI and CUF damage. During extended idle periods, these weather barriers (i.e. insulation and fireproofing) can deteriorate and lead to increased corrosion. Consideration should be given to removing insulation and fireproofing on equipment and piping systems that are shut down for extended periods of time or as part of the mothballing procedure, especially in moist and humid climates. Generally, corrosion rates of carbon and low alloy steels under insulation are significantly higher than atmospheric corrosion. Fully sealed mesh-reinforced chlorosulfonated polyethylene (CSPE) jacketing systems may be left in place.

6 Insulation and Fireproofing Systems

6.1 Insulation Materials and Thermal Insulative Coatings

6.1.1 ~~General~~ Insulation Material Types

Thermal insulation is important to facility operations yet is often overlooked and undervalued. These materials can be used in either low- or high-temperature applications. Low-temperature insulations typically include polyurethane, polyisocyanurate, flexible elastomeric foams, aerogels, and cellular glass~~,~~ ~~and phenolics~~. These insulation types normally require a vapor retarder~~barrier~~ under the outer weatherproofing to minimize the potential for vapor migration into/through the insulation~~condensation of atmospheric moisture~~. High-temperature insulations typically include perlite, calcium silicate, mineral wool, aerogels, ~~and~~ cellular glass and fiberglass. ~~For refinery and petrochemical plant applications, I~~insulation materials and thermal insulative coatings can be classified into one of the ~~six~~four categories listed below:

~~Granular~~ granular (rigid and flexible);~~;~~

a)

~~a) thin blankets;~~

b) fibrous;

cellular (foams);

c)

~~c) foams;~~

d) thermal insulative coatings.

Table 6 lists the various types that are generally encountered in refining and petrochemical plants, along with the applicable temperature ranges specified for each insulation material in the appropriate ASTM specifications. CUI has been reported under all ~~six~~ four types of insulation categories.

Table 6—Various Types of Insulation in Refining and Chemical Plants

Insulation Category	Material (ASTM)	Low Temperature Range		High Temperature Range	
		°F	°C	°F	°C
Granular - rigid	Calcium silicate (C533)	80	27	1700	927
	Expanded perlite (C610)	80	27	1200	649
Granular - flexible~~Thin blankets~~	Silica aerogel (C1728)	–321	–196	1200	649
	Microporous blanket insulation (C1676)	80	27	1200	649
Fibrous	Mineral wool (C547, C553, C592)	NS	NS	1400	760
	Fiberglass (C547, C553, C612, C1393)	NS	NS	1000	540
	~~High-temperature water-resistant stone wool (C547)~~ ~~Type II~~ ~~Type V~~	~~NS~~	~~NS~~	~~1200~~	~~649~~

		~~NS~~	~~NS~~	~~1400~~	~~760~~
Cellular (Foams)	Cellular glass (C552)	–450	–268	800	427
	Polyurethane	See NOTE	See NOTE	See NOTE	See NOTE
	Polyisocyanurate foam (C591)	–297~~100~~	–183~~73~~	300~~250~~	149~~121~~
	Elastomeric foam (C534)	–297	–183	350~~250~~	175~~121~~
	~~Polystyrene foam (C578)~~	~~–320~~	~~–196~~	~~165~~	~~74~~
	~~Phenolic foam (C1126)~~	~~–290~~	~~–180~~	~~257~~	~~125~~
Thermal insulative coatings	Thermal insulative coatings	40	4	500	260
NOTE Check with manufacturer for high and low temperature limits.					

6.1.2 Granular-~~type~~ Insulations

6.1.2.1 General

Granular insulations are composed of small nodules that contain voids or hollow spaces. These materials are ~~sometimes~~ considered open cell ~~materials~~ since gases can be transferred between ~~the~~ individual spaces. Calcium silicate and molded perlite insulations are considered rigid granular insulations. Silica aerogel and microporous blanket insulation are considered flexible granular insulations.

6.1.2.2 Calcium Silicate

Calcium silicate thermal insulation consists principally of hydrous calcium silicate usually reinforced with fibers. Some products will contain treatments (typically part of the insulation chemistry) to make them water repellent, to provide corrosion inhibiting properties and to minimize the potential for stress corrosion cracking. Calcium silicate insulation is available in different densities and as pipe sections (half shells, quads, hexes), flat block and curved segments. Table 7 lists relevant standard(s) for insulation properties.

Table 7~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Pipe Insulation Sections, Curved Segments	ASTM C533 - Type I
Flat Block	ASTM C533 – Type I, IA, II

~~Calcium silicate insulation is rigid pipe and block insulation composed principally of calcium silicate that usually incorporates a fibrous reinforcement. It is intended for use in high-temperature applications. If immersed in water at ambient temperatures, the material can absorb significant amounts of water (i.e. up to 400 % by weight). Even when not immersed in water, the material can absorb up to 25 % by weight water in high-humidity conditions because of its hygroscopic nature. Some products are water resistant and will shed bulk surface water if exposed prior to installation of jacketing. When exposed to water, the material has a pH of 9 to 10 and may be detrimental to alkyd or inorganic zinc coatings. Additionally, some manufacturers offer products with controlled or low chloride levels or offer products with corrosion inhibiting chemistries. The advantages and disadvantages for calcium silicate insulation are listed below.~~

~~a) Advantages:~~

  ~~1) low thermal conductivity;~~

~~2) available in a variety of shapes/sizes;~~

~~3) high compressive strength;~~

~~4) products with corrosion inhibiting chemistry and water resistance are available.~~

~~b) Disadvantages:~~

~~1) will absorb moisture;~~

~~2) fragile (i.e. brittle) and requires care to avoid breakage during installation;~~

~~3) chlorides can accumulate in service from the local atmosphere (some newer formulations have chemicals added to minimize this issue).~~

6.1.2.3 Expanded Perlite

Expanded perlite thermal insulation is composed principally of expanded perlite, silicate binders and may contain reinforcing fibers. Perlite is a volcanic material containing from 2 % to 5 % encapsulated water. It is a chemically inert substance composed primarily of silicon and aluminum dioxide. The perlite is expanded by means of rapid heating at a temperature between 1475 °F and 2200 °F (800 °C and 1200 °C). The vaporization of the encapsulated water results in the expansion of the perlite particles into a granular shape. ~~These particles have a granular shape.~~

Expanded perlite is chemically/thermally treated to make it hydrophobic and may also contain chemistry to provide corrosion inhibiting properties. Expanded perlite insulation is available as pipe sections (half shells, quads, hexes), flat block and curved segments. Table 8 lists relevant standard(s) for insulation properties.

Table 8~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Pipe, Flat Block, Curved Segments	ASTM C610

~~Perlite is a volcanic material containing from 2 % to 5 % encapsulated water. It is a chemically inert substance composed primarily of silicon and aluminum dioxide. The perlite is expanded by means of rapid heating at a temperature between 1475 °F and 2200 °F (800 °C and 1200 °C). The vaporization of the encapsulated water results in the expansion of the perlite particles. These particles have a granular shape.~~

~~Expanded perlite insulation, either rigid pipe or block, is composed of expanded perlite, inorganic binders, fibrous reinforcement, and hydrophobic additives. These hydrophobic additives begin to decrease in effectiveness at continuous exposure to temperatures above 400 °F (204 °C). The water resistance of the material is reduced at or above this temperature. Similar to calcium silicate, some manufacturers offer expanded perlite products with controlled or low chloride levels or offer products with corrosion inhibiting chemistries. The advantages and disadvantages for expanded perlite insulation are listed below.~~

~~a) Advantages:~~

  1) ~~water-resistant up to 400 °F (204 °C);~~
  2) ~~good compressive strength;~~
  3) ~~available in a variety of shapes/sizes.~~

b) ~~Disadvantages:~~
  1) ~~poor mechanical damage resistance (during handling and transportation);~~
  2) ~~more fragile than calcium silicate during installation;~~
  3) ~~water resistance will begin to oxidize at 400 °F (204 °C);~~

~~higher thermal conductivity compared to other insulation options.~~

~~6.1.3 Thin Blanket Insulations~~

~~6.1.3.1~~6.1.2.4 Silica Aerogel

Flexible aerogel blankets are insulation products made by combining aerogel with a flexible matrix material as carrier. Aerogel is a high porosity insulating material derived from a nanoporous structure formed by replacement of the liquid component of a silica gel solution with air. The matrix material may contain reinforcements, flame retardants and opacifiers which are sometimes added as either fibers or powders. The matrix material is normally a fibrous material, e.g. polyester, glass fiber, ceramic fiber or similar.

Flexible aerogel blankets are considered hydrophobic and open structure insulation materials. Their breathability allows water vapor transmission through its media, pushing out any moisture present against the insulated metal surface. For cryogenic and low-temperature service, flexible aerogel blankets may be manufactured with a factory-applied foil applied on one or both sides to prevent water vapor transmission. Table 9 lists relevant standard(s) for insulation properties.

Table 9~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Cold Service Product	ASTM C1728 – Type I, Grade 1B
Hot Service Product	ASTM C1728 – Type III, Grade 1A

~~Silica aerogel is comprised of a synthetically produced amorphous silica gel that has had its liquid phase replaced with air; these materials contain no crystalline silica. It is combined with a flexible fiber-based substrate for reinforcement. Due to their nanoporous structure and design, aerogels are strong insulators as they almost nullify convective, conductive, and radiative heat transfer.~~

a) ~~Advantages:~~
  1) ~~low thermal conductivity with reduced required thickness available;~~
  2) ~~product form allows for removal and reuse;~~
  3) ~~water-resistant up to 500 °F (260 °C);~~

  4) ~~wide range of operating temperatures.~~

~~b) Disadvantages:~~

  1) ~~hydrophobic performance will diminish at temperatures greater than 500 °F (260 °C);~~

  2) ~~slow moisture dissipation;~~

  ~~limitation of product form to wrap and not being available in pipe sizes leads to a nonwater tight system.~~

~~6.1.3.2~~6.1.2.5 Microporous Blanket Insulation

Microporous flexible, thin blanket insulation is primarily comprised of compacted inorganic metal oxide powders, powdered inorganic infra-red opacifiers and man-made or natural fibers or filaments. The compacted powder core is placed between E-glass fabric facings and quilted with E-glass thread creating a flexible composite blanket. These products are lightweight and can be flexible enough to form around 1 in. pipe. Although, intricate shapes can be difficult to wrap.

The insulation is available with a hydrophobic treatment which renders the material water repellant throughout the core, not just on the surface. The temperature is generally limited to higher than 75 °F (24 °C), though it can be used down to cryogenic temperatures with proper moisture retarder. Table 10 lists relevant standard(s) for insulation properties.

Table 10~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Quilted Panels	ASTM C1676 – Type II, Grade 2
Quilted Panels – Water Repellant (Hydrophobic)	ASTM C1676 – Type II, Grade 2 - Water Repellant

~~Microporous flexible thin blanket insulation is comprised of compacted fumed silica powder with reinforcing fibers, held together with a quilted fabric. This product contains no crystalline silica, requiring minimal PPE to install. These products can be flexible enough to form around 1 in. pipe. The microporous structure gives the insulation low thermal conductivity.~~

~~a) Advantages:~~

  1) ~~low thermal conductivity results in reduced thickness needed and lower profile;~~

  2) ~~hydrophobic surface treatment;~~

  3) ~~lightweight;~~

  4) ~~fast installation.~~

~~b) Disadvantages:~~

  1) ~~can be difficult to fabricate around intricate protrusions;~~

  2) ~~temperature limited to higher than 75 °F (24 °C);~~

  3) ~~hydrophobic performance will diminish at temperatures greater than 600 °F (316 °C).~~

~~6.1.4~~6.1.3 Fibrous-type Insulations

~~6.1.4.1~~6.1.3.1 General

This category of insulation materials includes mineral wool and fiberglass (glass wool) insulation. These materials are processed from molten state into fibrous form and combined with organic binders and formed into mandrel wound pipe sections, rolls and boards.~~pressed into rolls or sheets. Fibrous-type insulations are primarily intended for thermal and acoustic insulation; mineral wool and glass wool are also used for fire insulation in construction and industry~~.

~~Mineral wool and fiberglass have a lower compressive strength and are typically not considered walkable even under metal jacketing. Typically, upon oxidation of the binder at higher temperatures, the compressive strength of the materials decreases. Unless damaged, this will not impact the thermal performance. Similarly, the efficiency of the hydrophobic additives will be reduced at higher temperatures and under immersion conditions. Mineral wools are unattractive to rodents. (Temperature ranges for fibers, binders, and hydrophobic additives vary and should be verified with the manufacturer.)~~

~~6.1.4.2~~6.1.3.2 Mineral Fiber

Mineral fiber insulation is manufactured from mineral substance such as rock/stone, slag, or glass, processed from a molten state into fibrous form with binder. These fibers are classified into two general groups: fiberglass (glass wool) and mineral wool (rock/stone wool and slag wool). Note that many mechanical fiberglass products are typically lower density with maximum use temperatures of up to 1000 °F (540 °C) while mineral wool mechanical products are generally higher density with a maximum use temperature of 1800 °F (980 °C). There are exceptions and manufacturers' data should be consulted to ensure the maximum use temperature of the product is appropriate for its intended application.

Some products will contain treatments (typically part of the binder chemistry) to make them water repellent and/or topical coatings on the inside surface of the bore of the insulation to provide corrosion inhibiting properties. Certain product forms may also include facings and/or adhesives that can impact their maximum use temperature and flame spread / smoke generation index performance. Certain materials may require a heat-up schedule to prevent exothermic reactions. Table 11 lists relevant standard(s) for insulation properties.

Table 11~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Pipe Insulation – molded (mandrel wound)	ASTM C547 - Type I, II, IV, V
Pipe Insulation – precision v-groove	ASTM C547 - Type III
Blanket and Metal Mesh Covered Blanket Insulation	ASTM C553 – Type I, II, III, IV, V VI, VII ASTM C592 – Type I, II, III
Perpendicularly Oriented Mineral Fiber Roll and Sheet for Pipes and Tanks	ASTM C1393 – Type I, II, IIIA, IIIB, IVA, IVB
Mineral Fiber Board	ASTM C612 – Type IA, IB, II, III, IVA, IVB, V

~~Mineral wool insulation includes both stone wool and slag wool insulation, which are produced in the same way and comprised essentially the same raw materials, but in different proportions. Manufactures use a mechanized process to spin a molten composition of stone and slag into high-temperature-resistant fibers. Stone wool insulation is composed principally of fibers manufactured from a combination of~~

~~aluminosilicate rock (usually basalt), blast furnace slag and limestone or dolomite. Slag is a byproduct from steel production that would otherwise be landfilled.~~

~~Mineral wool insulations are vapor permeable. For this reason, mineral wool insulation is always used in combination with other materials for cryogenic applications where condensation can occur. Typically, in these cases the mineral wool is applied not for thermal, but for acoustic purposes. Mineral wool products may reach water resistance through the addition of hydrophobic additives during the fiberization process.~~

~~The advantages and disadvantages for mineral wool insulation are as follows.~~

~~Advantages:~~

~~lower thermal conductivity than calcium silicate and perlite;~~

~~resilient, light weight, and easy to install;~~

~~low leachable chloride content is available (typically <10 ppm);~~

~~open cell structure facilitates moisture dissipation and noise absorption.~~

~~Disadvantages:~~

~~not suitable for most cryogenic application;~~

~~low static compressive strength;~~

~~chlorides can accumulate in service because of water from the local atmosphere or process leaks.~~

~~6.1.4.3~~6.1.3.3 Fiberglass

Fiberglass has many similarities to mineral wool insulation. Fiberglass insulation is composed primarily of fibers manufactured from glass. The fibers are held together with a binder, typically a thermosetting resin, to form a blanket, board or pipe section geometry. Fiberglass products are produced in several different densities to satisfy different application requirements. Glass fiber insulations are lighter and generally have maximum use temperatures of up to 1000 °F (540 °C) ~~F~~. Needled or binderless glass fiber blanket products can have maximum use temperatures as high as 1400~~F~~ °F (760 °C).

Due to the nature of fibrous products, water vapor can pass easily through the material requiring the use of low permeability facings or jacketing to prevent water vapor migration for below ambient conditions. Fibrous insulation, unless treated with a water repellant agent, can wick water. Additionally, fibrous insulations do not provide compressive resistance on the same level as materials such as cellular glass or calcium silicate. Fiberglass insulation isn't typically used for pipe or structural support applications Table 12 lists relevant standard(s) for insulation properties.

Table 12~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Pipe Insulation – molded (mandrel wound)	ASTM C547 - Type I, IV
Blanket and Metal Mesh Covered Blanket Insulation	ASTM C553 – Type I, II, III, IV, V VI ASTM C592 – Type I
Perpendicularly Oriented Mineral Fiber Roll and Sheet for Pipes and Tanks	ASTM C1393 – Type I, II, IIIA, IIIB, IVA, IVB

Mineral Fiber Board	ASTM C612 – Type IA, IB, II, III
Layered, Glass Fiber Felt -Pipe and Board	ASTM C1937

~~Fiberglass is composed of pure glass containing various types of binders and is widely used as industrial insulation. Fiberglass has many similarities to mineral wool insulation. The advantages and disadvantages for fiberglass insulation are as follows.~~

~~Advantages:~~

~~noncombustible;~~

~~light weight;~~

~~easy to install.~~

~~Disadvantages:~~

~~compressing the material reduces its effectiveness;~~

~~absorbs water.~~

~~6.1.4.4 High-temperature Water-resistant Stone Wool~~

~~ASTM C547 Type II—High-temperature water-resistant mineral fiber insulation is capable of maintaining water resistance properties up to 482 °F (250 °C), the upper end of the CUI range, while maintaining all other performance characteristics of typical mineral fiber insulation, such as workability (easy to cut and manipulate) and low thermal conductivity. Insulation durability is maintainable up to 1200 °F (649 °C).~~

~~ASTM C547 Type V—Another option for high-temperature water-resistant mineral wool, this type of product can offer a denser mineral fiber product than a Type II product that can maintain product integrity up to 1400 °F (760 °C) with the ability to maintain water-resistant properties up to 482 °F (250 °C), the upper end of the CUI range. A Type V mineral fiber product maintains the same advantages and disadvantages of a Type II product.~~

~~a) Advantages:~~

  ~~1) offers all the advantages of conventional mineral fiber;~~

  ~~2) hydrophobic up to 482 °F (250 °C) and water repellency on par with the closed-cell insulation materials.~~

~~b) Disadvantages:~~

  ~~1) not suitable for most cryogenic application due to fibrous insulations permeability to vapors and condensation issue;~~

  ~~not recommended for cradle/saddle pipe support areas.~~

~~6.1.5~~6.1.4 Cellular-type Insulations

~~6.1.5.1~~6.1.4.1 General

Cellular insulations are classified as either open-cell structures where the cells aren't completely encapsulated ~~interconnecting~~ or closed-cell structures where the cells are fully encapsulated and sealed from each other. Generally, materials that have greater than 90 % closed-cell content are considered to be closed-cell materials.

This category of insulation materials includes cellular glass, polyurethane foam, polyisocyanurate foam, and flexible elastomeric foam.~~, polystyrene, and phenolic insulations. Except for flexible elastomeric insulation, they are classified as either rigid/closed-cell foams or flexible/closed-cell foams. Flexible elastomeric insulation is classified as flexible/closed-cell foam. These materials contain chlorides, fluorides, silicates, and sodium ions that can be leached from the insulation at temperatures above 212 °F (100 °C). The leachate produced can have a wide range of pH (i.e. 1.7 to 10). Accelerated corrosion can take place when the pH of the leachate is below 6.~~

~~6.1.5.2~~6.1.4.2 Cellular Glass

Cellular glass (also referred to as foam glass) is a lightweight, rigid insulating material consisting of millions of completely sealed glass cells, each an insulating space. This closed-cell insulation is composed of silica-based glass and made by adding powdered carbon to crushed glass and firing the mixture to form a closed-cell structure. It has low water vapor permeability and absorption characteristics, particularly useful in cold and cryogenic service applications. This insulation material does not wick water or liquids.

Cellular glass can be friable and brittle when subjected to mechanical abuse and can crack when subjected to rapid temperature change. The material can suffer damage from excessive vibration and can also be prone to damage when boiling water becomes trapped between the pipe and the insulation. Stress relief cracking of cellular glass can occur as the result of rapid temperature changes of more than 300°F (150°C) per hour. Table 13 lists relevant standard(s) for insulation properties.

Table 13~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Cellular Glass Standard	ASTM C552
Cellular Glass Test Methods	ASTM C240
Cellular Glass Fabrication Standard	ASTM C1639

~~Cellular glass (also referred to as foam glass) is a closed-cell insulation composed predominantly of silica-based glass. It is made by adding powdered carbon to crushed glass and firing the mixture to form a closed-cell structure. It is commonly used on electric-traced or steam-traced piping for freeze protection or process control.~~

~~The low permeability and absorption characteristics of cellular glass make it an attractive choice for cold service and cryogenic applications. This insulation material does not wick water or liquids, and is used in hot service where the nonabsorbent/nonwicking properties are desirable. The material has a thermal conductivity rating between mineral wool and calcium silicate and displays good compressive strength. It~~

~~can be friable and brittle when subjected to mechanical abuse and can crack when subjected to large temperature differences and thermal shock.~~

~~Cellular glass has the chemical resistance of glass. The material can suffer vibration-induced damage and can also be prone to damage when boiling water is trapped between the pipe and the insulation. Cellular glass cells may break down over time and trap water. Stress relief cracking of cellular glass can also occur at service temperatures above 450 °F to 500 °F (230 °C to 260 °C). The manufacturer should be consulted for the best method for insulating systems operating above 450 °F (230 °C).~~

~~The advantages and disadvantages for cellular glass insulation are as follows.~~

~~a) Advantages:~~

  ~~1) does not absorb water;~~

  ~~2) high resistance to mechanical damage when jacketed;~~

  ~~3) thermal conductivity does not deteriorate with aging.~~

~~b) Disadvantages:~~

  ~~1) susceptible to thermal shock if temperature gradient >300 °F (>150 °C);~~

  ~~2) easily abrades in vibrating service and fragile before application;~~

  ~~3) difficult to make good joints due to material brittleness and therefore susceptible to moisture ingress through joints;~~

  ~~4) moisture under insulation may not dissipate if low points are sealed vapor tight.~~

~~6.1.6 Foams~~

~~6.1.6.1 General~~

~~This category of insulation materials includes polyurethane, polyisocyanurate, flexible elastomeric, polystyrene, and phenolic insulations. Except for flexible elastomeric insulation, they are classified as either rigid/closed-cell foams or flexible/closed-cell foams. Flexible elastomeric insulation is classified as flexible/closed-cell foam. These materials contain chlorides, fluorides, silicates, and sodium ions that can be leached from the insulation at temperatures above 212 °F (100 °C). The leachate produced can have a wide range of pH (i.e. 1.7 to 10). Accelerated corrosion can take place when the pH of the leachate is below 6.~~

~~6.1.6.2~~6.1.4.3 Polyurethane Foam

Polyurethane foam is an organic, closed-cellular foams ~~-~~where all the tiny foam cells are packed close together with no interconnected pores. The foam cells are filled with a low-conductivity gas, which helps the foam to rise and expand.

Foams may be spray-applied or cast. For spray applications, typically ~~T~~two liquid components, an organic isocyanate compound (i.e. diisocyanate) and an alcohol (i.e. polyol), are mixed at high or low pressure using a spray gun with the reacting mix being sprayed onto the substrate. The spray application can provide a seamless seal and is typically produced on site and applied by certified applicators. Precast pieces are also available.~~ to provide a seamless seal. that can be installed by spraying or casting in the shop or field. Precast pieces are also available. Closed-cell foams are structures where all of the tiny foam cells are packed close together with no interconnected pores. The foam cells are filled with a low-conductivity gas, which helps the foam to rise and expand. Unfortunately, these cells can trap moisture in~~

~~contact with asset for prolonged periods. It is an insulation product that is typically produced on site and applied by certified applicators~~. ~~Two liquid components, an organic isocyanate compound (i.e. diisocyanate) and an alcohol (i.e. polyol), are mixed at high or low pressure using a spray gun with the reacting mix being sprayed onto the substrate to provide a seamless seal.that can be installed by spraying or casting in the shop or field. Precast pieces are also available.~~

Polyurethane foam is frequently used for preinsulated pipe joints. It has low permeability and absorption characteristics but can absorb water after prolonged service. In addition, these cells can trap moisture in contact with the surface for prolonged periods. Table 14 lists relevant standard(s) for insulation properties.

Table 14~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Spray-Applied	ASTM C1029

~~The advantages and disadvantages for polyurethane foam insulation are as follows.~~

~~Advantages:~~

- ~~1) low permeability and absorption characteristics (closed cell);~~
- ~~2) multiple product forms;~~
- ~~3) provides a seamless seal.~~

~~a) Disadvantages:~~

- ~~1) can be ignited and release toxic gases if exposed to an open flame;~~
- ~~2) sensitivity to ultraviolet (UV) radiation (sunlight);~~
- ~~3) can retain moisture in contact with underlying asset for extended periods;~~
- ~~4) can be vulnerable to some acids, caustics, solvents, hydrocarbons, and other chemicals;~~
- ~~5) susceptible to long freeze-thaw cycles; cells can break open and become filled with water.~~

~~6.1.6.3 Polystyrene Foam~~ ME note: Survey did not show this insulation material used significantly in Petrochemical applications.

~~There are two categories of polystyrene foam insulation:~~

~~1) expanded polystyrene (EPS) foam, and~~

~~2) extruded polystyrene (XPS) foam.~~

~~EPS foam is a closed-cell insulation that is manufactured by expanding a polystyrene polymer. It is usually white and made of pre-expanded polystyrene beads. It is an aromatic, thermoplastic polymer~~

~~made from the monomer styrene that is in solid (glassy) state at room temperature. When heated above 212 °F (100 °C), it flows sufficiently to permit molding or extrusion, becoming a solid when cooled.~~

~~XPS is a rigid, closed-cell insulation manufactured from solid polystyrene crystals. The crystals are fed into an extruder along with special additives and a blowing agent and melted into a viscous plastic fluid. After being forced through the extrusion die, the hot, thick liquid expands to become foam that is shaped, cooled, and trimmed to dimension. This continuous extrusion process produces a uniform closed-cell structure with a smooth continuous skin. EPS and XPS foams are primarily used as a cold system insulation material.~~

~~The advantages and disadvantages for polystyrene foam insulation are as follows.~~

~~a) Advantages:~~

  ~~1) low thermal conductivity;~~

  ~~2) high resistance to water and water absorption from freeze-thaw cycling;~~

  ~~3) resistant to photolysis.~~

~~b) Disadvantages:~~

  ~~1) like other organic compounds, polystyrene is flammable;~~

  ~~2) when burned without enough oxygen or at lower temperatures, polystyrene can produce a number of chemicals including polycyclic aromatic hydrocarbons, carbon black, and carbon monoxide, as well as styrene monomers, which can irritate eyes, nose, and respiratory system.~~

~~6.1.6.4~~6.1.4.4 Polyisocyanurate Foam

Polyisocyanurate (also known as polyiso or PIR) is an extruded foam, thermal insulation formed by a simultaneous blowing and polymerization process. PIR is produced by the manufacturer as rectangular "buns", typically 4 ft. (1.2m) wide x 3-24 ft. (0.9-7.3 m) long x 1-2 ft. (0.3-0.6 m) tall and then subsequently converted into insulation pipe sections, boards, and other shapes, as required, by a fabricator. PIR is considered a closed cell insulation material and is available in different densities and varied compressive strengths. Temperature range capability of PIR can vary between manufacturers but are generally -297°F (183°C) to 300°F (149°C). Table 15 lists relevant standard(s) for insulation properties.

Table 15~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Polyisocyanurate buns	ASTM C591

~~Polyisocyanurate is an organic, closed-cellular, rigid foam. It has low permeability and absorption characteristics and is typically used in cold service applications. The material has reasonable strength to provide resistance to light physical abuse. It has a low thermal conductivity. Disadvantages include combustibility and sensitivity to UV radiation (sunlight). Combustion may release toxic gases. Chemical resistance is generally good but can be vulnerable to some acids, caustics, solvents, hydrocarbons, etc. Polyisocyanurate foam is primarily used as a cold system insulation material.~~

~~The advantages and disadvantages of polyisocyanurate foam insulation are as follows.~~

~~a) Advantages:~~

  ~~1) low permeability and absorption characteristics;~~

  ~~2) multiple product forms.~~

~~b) Disadvantages:~~

  ~~1) like other organic compounds, polyisocyanurate is flammable;~~

  ~~2) when burned without enough oxygen or at lower temperatures, a number of chemicals are produced that can irritate eyes, nose, and respiratory system;~~

  ~~repeated freeze-thaw cycles can cause cells to break open and become filled with water.~~

6.1.4.5 Flexible Elastomeric Foams

Flexible elastomeric foam is a closed-cell cellular foam made of natural or synthetic rubber, or a mixture of the two, and containing other polymers, other chemicals, or both, which is permitted to be modified by organic or inorganic additives, including flame retardants. These foams have properties similar to those of vulcanized rubber, namely, the ability to be converted from a thermoplastic to a thermosetting state by cross-linking (vulcanization) and the ability to recover substantially its original shape when strained or elongated.

Flexible elastomeric foams are considered close cell structure insulation material, with good resistance to water vapor transmission. Normally flexible elastomeric foam insulation is applied under compression with joints and seams glued with dedicated system adhesive. Flexible elastomeric foam may be of different densities. Application at lower operating temperature is possible but has some limitations and requires special approach and risk assessment. Flexible elastomeric foam insulation is delivered in the form of sheets (rolls) and tubes. Table 16 lists relevant standard(s) for insulation properties.

Table 16~~:~~ - Insulation Property Standard(s)

Product Form(s)	**Standard**
Sheets, Rolls, Tubes	ASTM C534

~~6.1.7~~6.1.5 Thermal Insulative Coatings

Insulative coating materials are typically insulating materials suspended in resin. Insulating coatings are applied like spray-applied protective coatings. There are both organic resins (acrylic and epoxy) and inorganic resins such as polysiloxanes. The thickness typically ranges from 20 mils to 200 mils (0.5 mm to 5.0 mm) for organic coatings and may be significantly thicker for inorganic coatings. They are often used to provide burn protection and thermal insulation. In combination with an anticorrosive primer, these coatings also provide corrosion protection and help mitigate CUI. The maximum service temperature limit for the organic based coatings is approximately 350 °F (177 °C).

~~Advantages:~~

~~mitigates the risk of CUI if applied in combination with an anticorrosive primer;~~

~~minimal thickness required for personnel protection;~~

~~easily applied to irregular surfaces and restrictive spaces;~~

~~maintains thermal performance throughout service lifespan;~~

~~lower installation and maintenance cost (the damaged areas are easily removable and could be brushed or sprayed).~~

~~Disadvantages:~~

~~lower thermal efficiency (lower R-value per unit thickness) compared to other insulation materials;~~

~~narrower temperature range.~~

6.1.6 Insulation Material Properties Affecting CUI

The potential of corrosion from CUI can be influenced by specific material properties and chemistries of the insulation. Some example properties include the following:

a) Compressive strength – strength can be beneficial in supporting weather jacketing and potentially minimizing damage to it from mechanical impact.

b) Water absorption – the greater amount of water retained by the insulation material can influence corrosion where water ingress occurs.

c) Water vapor sorption - the greater amount of water vapor sorbed by the insulation material from the atmosphere can influence corrosion particularly in humid environments.

d) Wicking – the greater amount of water travelling into and through an insulation material by capillary action can influence corrosion similar to water absorption.

e) Leachable ions – the type and amount of water-leachable ions in an insulation material exposed to water can increase the corrosivity and stress corrosion cracking potential of the water.

Common standards exist that an owner-operator may reference to better understand the potential for corrosion from these example material properties and are shown in Table 17. Insulation material types have different properties, chemistries and characteristics so specific standards and test methods may not be applicable to all insulation types.

Table 17~~:~~ - Example Standards/Test Methods for Corrosion-Influencing Properties

Property	**Example Standard/Test Method(s)**
Compressive strength	ASTM C165
Water Absorption	ASTM C209 ASTM C240,

	ASTM C272, ASTM C610 EN13472 (ISO 12623) EN1609 (ISO 29767)
Water Vapor Sorption	ASTM C1104
Wicking	ASTM C1559
Leachable Ions	ASTM C871
Corrosion Resistance Carbon Steel (Mass Loss Corrosion Rate)	ASTM C1617
Corrosion Resistance: CUI	ASTM G189 AMPP TM21549
Corrosion Resistance: Austenitic Stainless Steel	ASTM C795

In addition, some specific corrosion-related concerns include:

1) Foam materials may contain chlorides, fluorides, silicates, and sodium ions that can be leached from the insulation at temperatures above 212 °F (100 °C). The leachate produced can have a wide range of pH (i.e. 1.7 to 10). Accelerated corrosion can take place when the pH of the leachate is below 6.

2) Most insulation materials absorb water whether directly exposed or from high humidity conditions. Water absorption is detrimental to thermal conductivity and to potential for CUI. The amount of water absorption can vary greatly between insulation materials (e.g. some up to 400% by weight). To minimize the potential of water absorption, the correct design of the insulated system as well as selection, installation and maintenance is important for good service performance. Note that when exposed to water, insulation materials can typically have a pH of 9 to 10 and may be detrimental to alkyd or inorganic zinc coatings.

3) Insulation materials which contain additives or treatments to improve their hydrophobic properties can experience decreased effectiveness after exposures to elevated temperatures or long-term exposure. Understanding the limitations of these additives, if any, is a consideration when assessing insulation systems for potential CUI.

6.2 Insulation Jacketing/Cladding

6.2.1 General

Regardless of the type of thermal insulation, keeping water out starts with ~~the~~ protective jacketing. In addition, jacketing systems ~~should also~~ protect the insulation from mechanical abuse and chemical attack. The functions performed by insulation jacketing include acting as a:

- barrier to protect the insulation and piping from weather (i.e. rain, snow, sleet, dew, wind, solar radiation, and atmospheric contamination) and deluge;
- vapor retarder to retard the passage of water vapor into the insulation;
- protective covering to prevent mechanical abuse (i.e. damage) of the insulation system by personnel, machinery, etc.;
- available with condensate or moisture retarders ~~barrier to prevent moisture condensation on~~to ~~the~~protect the inner surface of the metal jacket from corrosion~~ (sometimes called "moisture retarders")~~.

In many cases, jacketing may perform more than one of the functions listed above. For example, a metallic jacketing may serve as protection from both weather and mechanical abuse.

6.2.2 Jacketing Materials

6.2.2.1 General

Jacketing materials fall into two general categories, namely:

a) metallic jacketing, and

b) nonmetallic jacketing.

Metal jacketing is the most common jacketing material for insulation.

Metal~~lic~~ jacketing materials include aluminum, steel, and stainless steel. Nonmetallic jacketing materials such as mesh-reinforced CSPE and UV curing glass-reinforced plastic (GRP) are designed to be sealed systems to prevent the ingress of water as a strategy to prevent CUI. Some nonmetallic systems have proven to be less prone to mechanical damage.

6.2.2.2 Metallic Jacketing

Metal jacketing is supplied as thin sheets and can be smooth, corrugated, or embossed. The inner surface of metallic jacketing may be coated or covered with a moisture-resistant film to retard corrosion of the jacketing. The types of metallic jacketing materials include aluminum, aluminized steel, aluminum-zinc–coated steel, galvanized steel, and Types 304 and 316 stainless steel. The primary strengths of metallic jacketing are the long service life and the familiarity with its use in refinery and chemical plant applications. The primary weaknesses of metallic jacketing are the difficulty to effectively seal jacketing against moisture ingress and the vulnerability of joints to damage in service (i.e. from foot traffic). When using metal jacketing on ambient temperature and above insulation systems, it is important to pay attention to draining of the insulation system as a whole and to provide a means of escape for moisture that has entered through the jacketing.

Metal accessories such as banding, fasteners, washers, elbows, etc. for aluminum and stainless steel jacketing are typically Type 304 stainless steel, or Type 316 stainless steel for marine applications.

6.2.2.3 Nonmetallic Jacketing

6.2.2.3.1 General

Nonmetallic jacketing is designed to prevent the ingress of water, thereby eliminating one of the components necessary for corrosion to occur. Care should be taken to select only systems that can demonstrate high levels of performance in terms of low spread of flame, smoke and toxicity, longevity (particularly, resistance to UV), and mechanical robustness. System manufacturers should have a quality assurance procedure to determine that application quality meets best practice standards.

Nonmetallic systems may be either mesh-reinforced CSPE or UV-cured GRP.

6.2.2.3.2 Mesh-reinforced CSPE~~—~~

Systems comprise flat sheet material and factory preformed fittings for all bends, elbows, tees, endcaps, clamp covers and support collars, etc. up to 24 in. together with adhesive, sealant, and accessories. Systems are resistant to mechanical damage from foot traffic, etc.

The advantages and disadvantages of CSPE jacketing are as follows.

a) Advantages:

  1) sealed system prevents water ingress and thereby CUI;

  2) robust and resistant to mechanical damage;

  3) longevity (15 years field proven);

  4) easy maintenance and repair

  5) nondestructive testing by thermography;

  6) cost competitive with stainless steel.

b) Disadvantages:

  1) higher cost than aluminum.

labor intensive installation with higher skilled installer

6.2.2.3.3 UV-cured GRP~~—~~

Systems comprise flat uncured/wet sheet and factory preformed and cured fittings for all pipe sections, bends, elbows, tees, endcaps, clamp covers, and support collars, etc. up to 24 in. together with adhesive, sealant, and accessories. Systems are rigid and resistant to mechanical damage from foot traffic or other abuse. UV-cured GRP has poor resistance to UV and any areas exposed to UV should be coated and the coating maintained. Expansion joints are required to accommodate thermal expansion/contraction of piping.

~~The advantages and disadvantages of CSPE jacketing are as follows.~~

~~Advantages:~~

~~sealed system prevents water ingress and thereby CUI;~~

~~robust and resistant to mechanical damage;~~

~~longevity (15 years field proven);~~

~~easy maintenance and repair free;~~

~~nondestructive testing by thermography;~~

~~cost competitive with stainless steel.~~

~~Disadvantages:~~

~~higher cost than aluminum.~~

~~labor intensive installation with higher skilled installer~~

The advantages and disadvantages for UV curing GRP are as follows.

a) Advantages:

  1) sealed system prevents water ingress and thereby CUI;

  2) robust and resistant to mechanical damage.

b) Disadvantages:

  1) higher cost than aluminum and stainless steel;

  2) requires coating when exposed to UV, which needs to be periodically maintained.

  ~~2)~~3) labor intensive installation with higher skilled installer

6.2.2.4 Jacketing Thickness

ASTM C1696~~-16 *Standard Guide for Industrial Thermal Insulation Systems*~~ has presented guidelines for jacketing thickness on piping, vessels, and storage tanks.

6.3 Caulking

~~Caulking is used to seal insulation seams.~~ Caulking is used to create a seal at junctions, terminations, and penetrations in the insulation system covering to prevent the ingress of water. Over time, insulation caulking dries out, cracks, and loses its seal, so it is imperative to inspect for caulking deterioration and renew/replace damaged caulking to prevent moisture ingress.

Once the metal jacketing is applied, the seams are often caulked with silicone or other type of sealant to prevent the ingress of water through the lap. In addition, there are extremely low permeability rated products such as polyvinylidene chloride resins that lock out oxygen and moisture. It is frequently used on urethane, XPS foam, and foam glass because of their excellent vapor ~~barrier~~ retarding properties. Additional information is available in ~~9~~8.8.3.

Sealant applied as part of the mesh-reinforced CSPE nonmetallic jacketing system is a specifically developed high performance sealant that is not subject to the above degradation process and delivers proven longevity in excess of 25 years with evidence to support in excess of 40 years in high UV locations.

6.4 Fireproofing Materials

6.4.1 General

There are a variety of fireproofing materials, each with their own unique physical and chemical properties. Factors to consider when selecting a material for a fireproofing application include:

- weight limitations for supports (particularly for heavyweight concrete applications);
- fire resistance rating (in hours);
- adhesion strength and durability;
- ease of application and repair;
- corrosiveness of the atmosphere;
- corrosiveness of the fireproofing to the substrate;
- nonfire operating temperature limitations;
- anticipated life of the fireproofing material;
- maintenance requirements;
- potential for damage during maintenance operations;
- cost;
- application methods.

A discussion of the various generic types of fireproofing is presented below.

6.4.2 Dense Concrete

Concretes made with Portland cement that have densities between 140 lb/ft^3 and 150 lb/ft^3 (2200 kg/m^3 and 2400 kg/m^3) are considered dense concretes. They can be formed in place or pneumatically sprayed to the required thickness using steel reinforcement. They are durable and can withstand thermal shock from impingement from fire hose streams.

a) Advantages:

  1) withstands thermal shocks and fire hose streams;
  2) withstands flame exposure up to 2000 °F (1100 °C);
  3) performance extensively proven (±4 h protection).

b) Disadvantages:

  1) high weight;
  2) high thermal conductivity;
  3) installation costly and time consuming;
  4) moisture absorption can lead to cracking and spalling in freezing climates.

6.4.3 Lightweight Concrete

Instead of using gravel as aggregate, lightweight concretes use very light aggregate such as vermiculite or perlite with cements that are resistant to high temperatures. Lightweight concrete densities range between 25 lb/ft^3 and 80 lb/ft^3 (400 kg/m^3 and 1300 kg/m^3). Though usually applied by pneumatic spraying, they can also be troweled or poured in place. Pneumatically sprayed material is denser than troweled or poured concrete.

a) Advantages:
   1) lightweight material with better fire protection properties than dense concrete;
   2) can withstand flame exposure up to 2000 °F (1100 °C);
   3) can withstand thermal shocks and hose streams.

b) Disadvantages:
   1) porous material;
   2) moisture absorption leads to cracking and spalling in freezing climates;
   3) more susceptible to mechanical damage than dense concrete.

6.4.4 Other Spray-applied Fire-resistant Materials

6.4.4.1 General

This category of fireproofing materials includes subliming and intumescent mastics, ablative coatings, intumescent epoxy coatings, and inorganic coatings that are spray applied.

a) Advantages:
   1) lightweight material with better fire protection properties than dense concrete;
   2) can withstand flame exposure up to 2000 °F (1100 °C);
   3) can withstand thermal shocks and hose streams.

b) Disadvantages:
   1) porous material;
   2) moisture absorption leads to cracking and spalling in freezing climates;
   3) more susceptible to mechanical damage than dense concrete.

6.4.4.2 Sprayed Organic Coatings Subliming Mastics/Intumescent Mastics/Ablative Coatings

Sprayed organic coatings are thin when compared to sprayed inorganic coatings. These materials are classified as either intumescent mastics, ablative coatings, or subliming compounds.

Intumescent mastics are normally composed of epoxy-based materials that expand when exposed to fire to form an insulating char with a low thermal conductivity. This insulating char acts as a thermal barrier between the fire and the substrate. During this reaction, toxic fumes and smoke are released at temperatures above 570 °F (300 °C). As a result, intumescent mastics are not suitable for enclosed areas such as accommodation modules or temporary safe refuge areas on offshore structures.

Ablative coatings are organic coatings that gradually erode under fire exposure because of the absorbed heat energy from a fire that changes the virgin solid coating into a gas composite. This action prevents heat absorption into the underlying substrate.

Ablative coatings are organic coatings that need large amounts of energy to decompose or break down. They are designed to reduce the rate of burn and usually contain fire retardant chemicals such as aluminum trihydrate or antimony oxide. When exposed to fire, these coatings start to ablate by chemical and physical reactions (i.e. evaporation, chemical cracking, or melting) and in the process, consume large amounts of heat energy while keeping the underlying substrate relatively cool for a certain length of time. The gases and vapors generated during the ablative process push oxygen away from the surface, dilute flammable gases preventing them from burning, and interrupt the “chain reaction” of the fire chemically. After decomposition of all organic components, a solid structure of inorganic components remains offering further protection by insulation.

Subliming compounds have an active ingredient that absorbs heat as it changes from the solid to a gas phase (i.e. sublimation). Similar to ablative coatings, subliming compounds are added to provide an additional layer for insulation. The effectiveness of subliming compounds is a function of various elements including the coating material thickness, compounds’ sublimation temperature and enthalpy at sublimation, heat capacity of the substrate, and fire exposure. The fire depletes the subliming compounds. Therefore, once exposed, the protection provided by the compound is reduced or eliminated.

a) Advantages:
   1) quick application;
   2) lightweight;
   3) suitable for use on existing supports that may not handle additional weight.

b) Disadvantages:
   1) can be stripped away by firefighting activities and flash fires;
   2) susceptible to abrasion and mechanical damage.

6.4.4.3 Sprayed Intumescent Epoxy Coatings

A wide range of intumescent epoxy coatings are available. These can be described as a mix of thermally reactive chemicals in a specific epoxy matrix formulated for fireproofing applications. Under fire conditions, they react to emit gases, which cool the surface while a low-density carbonaceous char is formed. This char then serves as a thermal barrier.

a) Advantages:
   1) high bonding and corrosion protection;
   2) lightweight and durable under nonfire conditions;
   3) good durability in severe impingement jet fire tests.

b) Disadvantages:
   1) possible char coating damage during fire if subjected to impingement from fire hose streams;
   2) requires expertise in application and may require multiple coats or special equipment to apply dual components simultaneously;
   3) some concerns regarding potential toxicity of gases generated during fire conditions;

    4) sprayed coatings on loose components, such as valve/actuator covers, require care when handling in freezing conditions.

6.4.4.4 Sprayed Inorganic Coatings

This class of materials is referred to as lightweight cementitious fireproofing materials and is usually based on cement with a lightweight insulating aggregate of exfoliated vermiculite. They provide exceptional dimensional stability under hydrocarbon fire exposure conditions. The exfoliated vermiculite has the capacity to relieve stresses created by both hot and cold thermal shock when subjected to simultaneous exposure to fire and water impingement. These vermiculite cements can perform equally well in multiple fires where no repair or replacements have been carried out.

Vermiculite cements are noncorrosive to the structural or vessel surfaces. They are noncombustible and do not produce toxic fumes during their exposure to fire. Since they are organic, they do not degrade with time. There are examples of applications that have been in service for more than 40 years with little evidence of damage or corrosion to the underlying substrate.

a) Advantages:

    1) lightweight;

    2) vermiculite allows for denting instead of cracking or shattering;

    3) noncombustible and nontoxic when exposed to fire.

b) Disadvantages:

    1) properties vary greatly with composition;

    2) not suitable for high-vibration areas;

    3) ~~great~~ care should be taken to ensure proper application thickness.

6.4.5 Preformed Inorganic Panels or Masonry

6.4.5.1 General

These types of materials for fireproofing are focused on reducing installation costs and time. They also facilitate reductions in weight and overall volume contribution to a structure thereby enhancing the operating efficiency of the equipment.

6.4.5.2 Preformed Inorganic Panels

Preformed, or prefabricated, fireproofing panels are based off many of the attributes commonly associated with intumescent epoxy coatings: ease of application, reduced application times, reduced weight and volume contribution, etc. Yet this form of passive fireproofing stands out on its own if only for the fact that it offers several unique advantages as follows.

a) Advantages:

    1) reduced tie-in connections/field joints;

    2) reduced steel erection costs and damage;

    3) lower maintenance costs;

    4) installation work unaffected by environmental conditions;
    5) easy access for inspection;
    6) clean application;
    7) no curing time;
    8) low thermal conductivity.

b) Disadvantages:
    1) labor intensive installation when instrumentation/appurtenances attached to columns;
    2) susceptible to impact damage.

6.4.5.3 Masonry Blocks and Bricks

This category of insulation materials includes refractory clays and other ceramic materials. These materials are not common for new construction but are present in existing facilities. Advantages and disadvantages for masonry blocks/bricks are shown below.

a) Advantages:
    1) easy installation;
    2) lightweight;
    3) availability in a wide array of sizes.

b) Disadvantages:
    1) high installation costs;
    2) high maintenance;
    3) admits moisture and cracks through joints in the masonry.

6.4.5.4 Endothermic Wrap Fireproofing

This flexible, tough, inorganic sheet material with a bonded aluminum foil outer layer is formed from a maximum of inorganic, highly endothermic filler and a minimum of organic binder and fiber. An endothermic wrap when exposed to high temperatures keeps heat out by releasing chemically bound water to cool the outer surface used to protect structural steel, and electrical cable trays/circuits in conduits.

It can be wrapped around a wide variety of potentially exposed vulnerable equipment. These wraps provide electric cable trays with rated performance under ANSI/UL 1709 (or functionally equivalent) conditions. ANSI/UL 1709 covers small- and full-scale test methods to measure the resistance of protective materials to rapid-temperature-rise fires. In most applications, the wrap is held in place by stainless steel bands with foil tape and/or fireproofing caulk on seams, gaps, and termination points. For structural steel in new construction, surface preparation of the substrate should include fresh prime coating to provide corrosion protection.

a) Advantages:
    1) systems are easily reentered/repaired, allowing retrofitting over steel without dissembling wiring and other attached items;
    2) can be applied directly over existing cement or block where additional protection required;

3) flexible endothermic wrap systems are explosion rated.

b) Disadvantages:

1) should be weatherproofed or stainless steel-jacketed when used outdoors;

2) weatherproofing should be done with manufacturer-specified protection tape to preserve recommended protection.

6.5 Coatings Under Insulation and Fireproofing Systems

6.5.1 General

When moisture penetrates insulation and fireproofing systems, the surface of the underlying component will be subjected to corrosion. In many situations, users apply coatings to the surface of the component before applying insulation or fireproofing. Selecting the right coating is extremely important since the coating is the last line of defense for keeping the electrolyte from the metal surface and preventing corrosion. Users should inspect new coating installations for holidays and make repairs to any holiday.

6.5.2 Factors to Consider When Selecting a Coating System

There are a variety of issues that should be considered prior to selecting a coating for equipment that will be insulated. These include the following.

— Under dry conditions, what is the maximum exposure temperature for the coating?

— What is the maximum temperature resistance of the coating under immersion conditions?

— What is the level of surface preparation required?

— Is the coating product a single-component or multicomponent product?

— What is the single coat dry film thickness?

— Can the coating be recoated?

— What is the maximum surface temperature?

— What is the ambient temperature and humidity that may affect the coating system?

6.5.3 Coating Systems

Examples of coating systems used under thermal insulation and fireproofing are presented in NACE SP0198. The document discusses the suitable temperature ranges and surface preparation/surface profile requirements for each coating system as well as the suggested prime coat and topcoat for each system. Coatings systems that are often used in these applications include:

— high-build epoxy systems;

— epoxy phenolic systems;

— epoxy novolac systems;

— air-dried or modified silicone systems;

— inorganic copolymer systems or inert multi-polymetric coating systems;

— fusion-bonded epoxies;

- ~~thermal spray aluminum (~~TSA ~~) (~~with or without a thinned epoxy sealer or silicone coating~~)~~;
- petrolatum or petroleum wax tape systems.

6.5.4 Surface Preparation

The key element to the long-term performance of a coating system is how well the surface is prepared to receive the coating. Standards for surface preparation have been developed by various organizations including the ~~Society for Protective Coatings (SSPC), NACE International~~AMPP (formerly Society for Protective Coatings (SSPC) and NACE International)~~-~~, the Canadian General Standards Board (CGSB), the Swedish Institute for Standards (SIS), and the British Standards Institution (BSI). A comparison of these standards is shown in Table ~~9~~18.

Table 18~~7~~—Comparison of Surface Preparation Standards

System	SSPC	SSPC/ NACE	CGSB	SIS	BS
Solvent clean	SP-1	—	—	—	—
Power tool clean	SP-3	—	31 GP 402	St. 3	—
White-metal blast	~~SP-5~~	SP-5 / No.#1	31 GP 404 Type 1	Sa. 3	BS4232 first quality
Commercial blast	~~SP-6~~	SP-6/ No.#3	31 GP 404 Type 2	Sa. 2	BS4232 third quality
Brush-off blast	~~SP-7~~	SP-7/ No.#4	31 GP 404 Type 3	Sa. 1	Light blast to brush-off
Near-white blast	~~SP-10~~	SP-10/ No.#2	—	Sa. 2 $^{1}/_{2}$	BS4232 second quality
Power tool cleaning to bare metal	SP-11	—	—	—	—

For newly installed piping, CUI concerns are frequently addressed by the use of high-quality protective coatings or TSA. However, this solution can be expensive for use in remediation. This high cost of remediation has contributed to the current industry challenges associated with CUI. Therefore, one should consider initial long-term prevention options. This cost and value of an initial prevention option may be assessed using a life cycle analysis based on the remediation method selected. This analysis should consider the remediation costs, the future inspection costs, and the costs associated with loss of containment as the result of failure of the equipment pressure boundary, etc. The surface preparation for the application of most epoxy or metal filled coatings can be extensive; some require grit blast to white metal. In some cases, the best alternative for remediation is to replace the entire section with new pipe.

For fireproofing, it is important to verify that the external coating is compatible with the fireproofing system.
Since coatings have a finite life, they may need to be renewed periodically to protect equipment and piping from CUI. Inorganic zinc coatings without a topcoat are prone to rapid failure in the presence of moisture. For example, calcium silicate insulated piping, when exposed to water, can generate an environment with a pH of 9 to 10 on the wetted pipe surface. This environment may be detrimental to alkyd and inorganic zinc coatings and can lead to pitting at the joints between the blocks of insulation. Inorganic zinc coatings used without a topcoat on structural steel being fireproofed are generally not effective since zinc is amphoteric. This is because the alkaline conditions beneath concrete and cementitious fireproofing can promote corrosion of the inorganic zinc coating. For carbon and low alloy steels, TSA coating offers superior protection if well applied (see 11.5.4). For stainless steel, aluminum foil wrapping is very effective in protecting the surface from ECSCC. NACE SP0198 provides guidance on the use of protective coatings to mitigate corrosion under thermal insulation and fireproofing materials.

7 Inspection for CUI and CUF Damage

7.1 Inspection Planning

7.1.1 Determining CUI Susceptible Pressure Equipment

Determining which pressure equipment is susceptible to CUI/CUF can first involve defining the criteria that make CUI/CUF a credible damage mechanism. The presence of insulation, fireproofing and operating metal temperature ranges of the pressure equipment are a common starting point. Refer to Section 4.2 and 4.3 for guidance on typical criteria which owner-operators can use to define their own specific criteria.

Available data for pressure equipment is compared against the criteria and CUI/CUF is assigned as a credible damage mechanism to that equipment meeting the criteria. This equipment becomes part of the inspection program for CUI/CUF.

7.1.2 Prioritizing CUI Inspections

When implementing a CUI/CUF inspection program, owner-operators have also used additional criteria to prioritize pressure equipment inspection. The additional criteria are often related to the potential likelihood of CUI damage. Some examples include:

a) age of equipment,
b) the type of insulation,
c) the size and complexity of the insulated equipment,
d) the presence, type, effectiveness and age of any protective coatings and moisture barriers,
e) the operating metal temperature versus industry-reported potential corrosion rates,
f) external environment such as cooling tower overspray,
g) presence of steam tracing,
h) geographic location and proximity to water,
i) type of process unit.

These criteria may be found in historical records or specifications.

There are a variety of approaches and methodologies that can be employed in conducting CUI/CUF likelihood assessments. Annex A, Examples of Likelihood Assessment Systems, presents an example of a simplified qualitative points-based approach and a simplified semi-quantitative score-based approach. Owner-~~Operators~~ operators may develop specific parameters and ranges to assist in determining the likelihood of CUI/CUF of specific equipment based upon their criteria and experience.

7.1.3 Visual Examination Method (VT) / Field Survey without Removal of Insulation/Fireproofing

Visual examination of the insulated pressure equipment is a common early step in implementing a CUI inspection program and for the inspection for CUI. In fact, the field survey may be part of prioritizing CUI inspections. The visual examination/field survey captures CUI -focused data of the actual pressure equipment that may not be captured in historical equipment visual examination records. This includes key criteria such as confirming the presence and/or lack of insulation on the equipment or recording areas of damage to the insulation jacketing. Many owner-operators rely on this field survey by the inspector to identify locations with signs of potential CUI and locations with features where CUI would be more likely to occur. Examples include:

a) Signs of wetness
    1) Bulged areas of insulation
    2) Rust staining
    3) Wet Jacketing or insulation
    4) Areas exposed to steam tracing leaks
    5) Jacketing with mold or organic growth

b) Poor Installation or insulation system damage

    1) Missing bands or jacketing
    2) Damage due to foot traffic or vibration
    3) Missing caulking on insulation jacketing
    4) Insulation jacketing seams on the top of horizontal piping or oriented preventing watershed
    5) Inspection ports without covers or plugs

c) Areas where water could travel from one location to another, can gather or trap and cooler areas where condensation often occurs
    1) Control valve loops
    2) Pump suction and discharge lines
    3) Bottom of vertical pipe runs
    4) Isolated sections of insulation including areas insulated solely for personnel protection
    5) Inner radius and bottom of outer radius of vertically oriented ells and inner radius of vertically oriented tees.
    6) Intersection of vertical-down piping branch connections on horizontal piping systems
    7) Above insulation support and stiffening rings
    8) Sagging horizontal runs of piping adjacent to damage or suspect areas

d) Penetrations or breaches in the insulation jacketing system
    1) Insulation penetrations such as heat trace tubing or instrument lines
    2) Insulation terminations at flanges and other piping components
    3) Vents and drainpipe
    4) Hangers and supports
    5) Bolted-on pipe shoes

Owner-operators often establish what features and characteristics indicate the potential relative severity of potential CUI/CUF. An example of this is shown in Figure 6. This data is typically recorded on a checklist. An example of CUI Visual Inspection Checklist is presented in Annex C.

The data from the survey is often the basis for developing an inspection plan to identify the presence and extent of damage. An example of that is where the total number of suspect locations on a piping system is used in conjunction with API 570, Table 2 (~~2—~~Recommended Extent of CUI Inspection Following Visual Inspection for ~~susceptible~~ Susceptible Piping) to define the number of locations to follow up with examination.

Owner-~~Operators~~ operators will typically establish procedures to govern the selection of and number of locations to be examined based upon the visual findings and often times, other critieria.

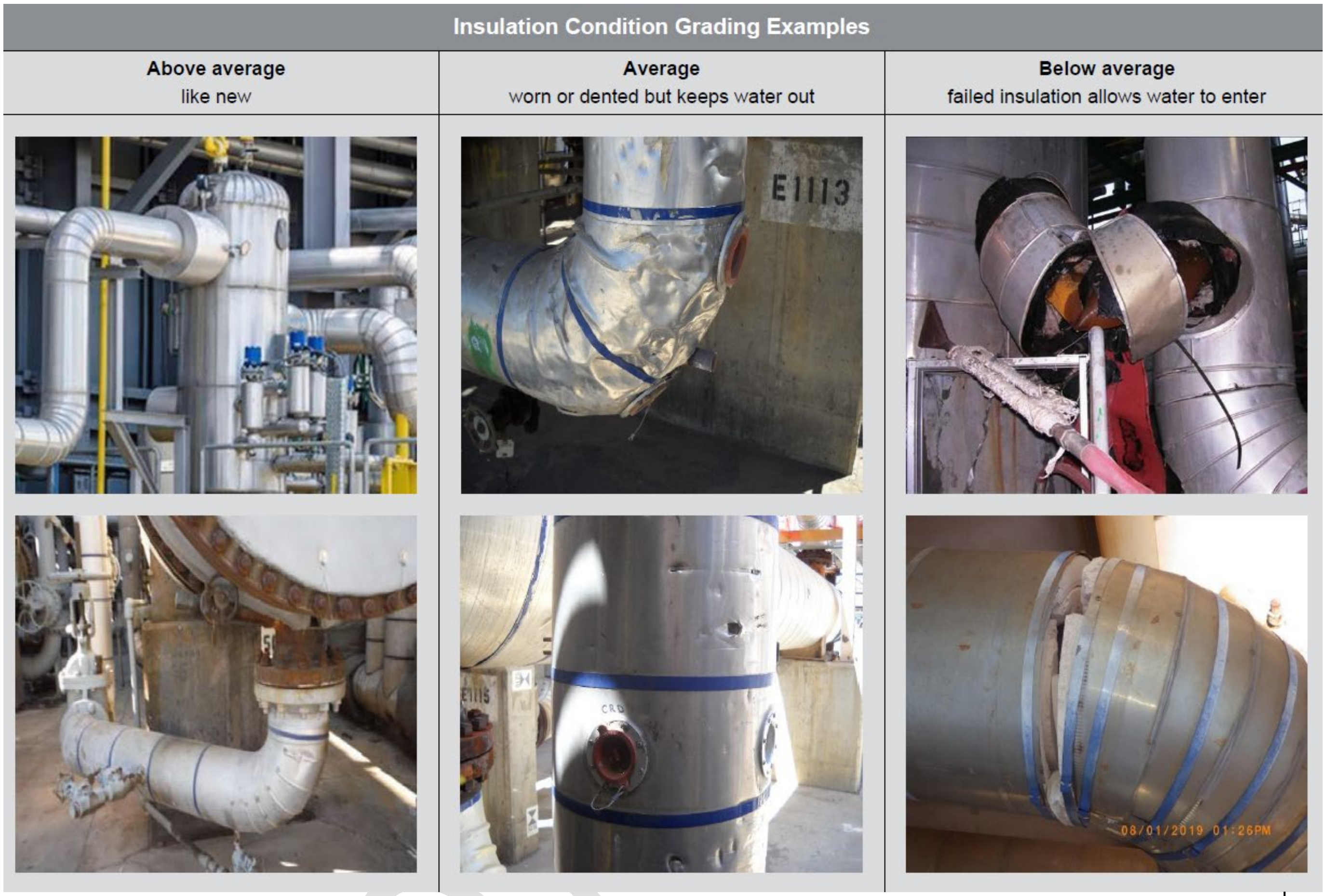


Figure 6~~:~~ - Example of an Insulation Grading System

7.1.4 Strategies for Implementing and Maintaining CUI Inspection Programs

Many owner-operators implementing comprehensive CUI/CUF inspection programs intiate this work through a special emphasis program. Defining, prioritizing and establishing CUI/CUF inspection activity for specific equipment often requires a focused effort and resources beyond the routine external visual examinations performed on equipment. Visual external inspections of equipment should identify and report obvious signs of poor insulation covering, lack of sealing, rust stain marks, etc. for insulation maintenance. However, these typically may not involve insulation removal and appropriate NDE methods to find areas of wet insulation and CUI damage in order to provide increased assurance against leaks due to CUI/CUF.

Once comprehensive CUI/CUF inspection programs are implemented, CUI/CUF examinations should be performed regularly per the established inspection plan. These often times will be done as part of the equipment inspection plan rather than as a special emphasis program.

7.1.5 Risk-Based Inspection

(ME NOTE: RBI moved from Section 8 and changes highlighted in red)

CUI/CUF inspection programs may be based upon risk through risk-based inspection (RBI). The results of a semi-quantitative RBI assessment may be used to develop inspection plans that will maintain the risk associated with the components at or below target values established by the owner-operator. For equipment potentially affected by CUI/CUF, the purpose of ~~risk-based inspection (~~RBI~~) should be~~ is to:

- identify the asset/component susceptibility to CUI/CUF and damage ~~mechanisms/~~modes;
- provide an assessment of the risk of CUI/CUF, through a probability and consequence evaluation; and
- develop a prioritized CUI/CUF inspection plan to manage risk.

An RBI assessment may be used to increase or decrease the inspection frequency and scope of CUI/CUF inspections when compared to time-based or condition-based inspection planning.

RBI assessments and programs, when elected to be utilized by the ~~owner/user~~owner-operator, shall be fully documented by the owner user. As an example, descriptions for the establishment of an RBI program can be found in API 580, and descriptions of a semi-quantitative RBI methodology are provided in API 581. The user may elect to use these documents for specific guidance, but other documentation does exist in the industry and the only requirement is to document the accepted program and methodology.

For any RBI program, it is very important that data used in the analysis be of good quality and acceptable by the ~~owner/user~~owner-operator as representative of the current state of the equipment and insulation. For CUI/CUF, data that pertains to the physical condition of the component should only be obtained from a documented field (external) inspection, which should be incorporated into the planned API 510, API 570, and API 653 external inspection programs.

When establishing a risk analysis method, it should be noted that this document provides examples of the information required to create an assessment of the probability of failure (likelihood) due to CUI/CUF damage. Also, the assessment of the consequence of failure shall~~must~~ conform to a documented ~~owner/user~~owner-operator consequence assessment process. API 580 and API 581 can provide guidance for this.

After a risk assessment (RBI analysis) has been completed, the findings should be prioritized for best risk mitigation and/or risk reduction. For example, highly suspected locations and/or areas for CUI/CUF, such as penetrations and visually damaged insulation/fireproofing areas, should be considered as higher priorities during inspection plan development. Additionally, suspect locations, activities, and the surrounding area should also be closely examined for the potential of implementing engineering changes that could mitigate or eliminate the risk of CUI/CUF. Examples of areas of concern for inspection planning are provided in this document and in API 581.

~~7.1.5~~7.1.6 Insulation Removal Evaluation

Before performing CUI inspections and evaluations with insulation removal, t~~T~~he purpose of the insulation on equipment and piping should be well understood~~ before performing CUI inspections~~. This can help establish priorities, determine what hazards may exist, determine if insulation can be removed while equipment/lines are in operation, and determine if insulation can be permanently removed. In fact, one of the big benefits from this insulation evaluation process is that it can actually discover many areas do not really require insulation so permanent removal results in 100 % elimination of CUI risk. A management of change (MOC) process should be used when considering modification or removal of any insulation or fireproofing.

As part of an insulation removal evaluation, the following list of questions may be helpful to review prior to executing CUI inspections.

- Is equipment/piping in cyclic service? If yes, what are the maximum temperatures expected and duration of maximum temperature?

- Is equipment/piping in intermittent service? If yes, what is the frequency of operation?
- Is equipment/piping subject to steaming and/or hot gas treatment? If yes, what are the frequency, maximum temperature, and the duration?
- Can the insulation be removed for CUI inspection and remediation while the equipment/piping is in service without adversely affecting process control, product quality, and safety?
- Is equipment/piping currently out-of-service?
- Is insulation installed for the sole purpose of personnel protection (>140 °F)? If yes, can metal cages or ceramic coatings be used instead of insulation?
- Does the equipment/piping contain fluids that may freeze resulting in an interruption of service(s)?
- Does the equipment/piping need insulation for process control/unit production? If yes, would wind and rain guards suffice?
- Does the equipment/piping require heat tracing? If yes, is the heat tracing used continuously or only if certain conditions exist?
- Does the equipment/piping require insulation to reduce condensation?
- Does the equipment/piping require insulation for acoustics?
- Does the equipment/piping require insulation for fire protection or controlling pressure relieving events?
- Do the heat conservation economics dictate this equipment/piping require insulation [usually considered at >200 °F (>93 °C)]?

When assessing the possibility of permanently removing thermal insulation, it may be useful to review the flow chart on the need for insulation presented in IMMM EFC 55.

7.2 Specific Inspection Applications

~~7.1.6~~7.2.1 Inspection of Piping Operating Below 32 °F (0 °C)

A common source of moisture on piping operating below 32 °F (0 °C) is water vapor penetrating the insulation system where jacketing is damaged or jacket seams and vapor retarder~~barrier~~ mastics are compromised. Ice may form during operation where water vapor penetrates. Insulated piping and equipment with a layer of ice do not corrode significantly because of the low temperature and limited oxygen concentration. However, the ice-to-air interface provides an ideal location for corrosion to occur as the result of freezing and thawing cycles that can occur as the result of operating condition or periodic shutdowns. The ice-to-air interface (i.e. transition points) should be a focal point of CUI inspections.

In these services, the removal of insulation on operating equipment is undesirable because wet and icy conditions make it difficult to inspect. It also exposes the insulation to atmospheric water vapor, trapping more moisture within the insulation prior to re-insulation of the area. Even though insulation removal is possible with a well-thought-out and well-executed plan to minimize the impact of ice formation, the primary inspection method to consider for these transition points is profile radiography. Profile radiography can be conducted using film, a photostimulable phosphor (PSP) plate, or a digital radiographic system without removing the piping from service. In addition, pulsed eddy current examination method (PEC) can be utilized to assess relative damage in locations where the insulation is not distorted because of ice formation. Any of the inspection methods discussed in 7.3 can be utilized when the piping has been removed from service.

7.2.2 Inspection and Evaluation of External Corrosion “Scabs”

The inspection and assessment of external corrosion (e.g., CUI scabs) should carefully consider the potential for failure from mechanical disturbance of the scale, as well as the performance of NDE techniques to measure remaining wall thickness. While visual inspection of the surrounding area and scale thickness can be informative, the scale may have been previously disturbed and therefore may not be indicative of the total corrosion that has occurred.

Other NDE methods such as radiography (tangential and density) can be helpful, but they can have significant measurement error due to the amount of remaining scale on the surface or highly irregular nature of the wall loss pattern. Electromagnetic methods such as pulsed eddy current can provide average wall loss, but the localized pitting will likely be underestimated.

Some experience with ultrasonic techniques (similar to those used to inspect for contact point corrosion) may also be helpful, but Owner-operators should consider the size of the corrosion scab and how its shape will affect wall thickness measurement accuracy.

7.3 Visual Inspection and NDE Techniques~~Tools and Methods~~

(ME NOTE: that significant content changes occurred in section 7.3: Visual Inspection and NDE Techniques. Most often the old content is shown as deleted even though some portions may be imbedded in the new content.)

~~7.1.7~~7.3.1 General

Section 7.3 covers visual inspection and various NDE techniques for the detection and evaluation of CUI/CUF on equipment and structural supports. ~~There~~ These inspection methods are characterized as either~~both~~ direct ~~and~~or indirect.~~ inspection methods for detecting surface corrosion damage (i.e. CUI or CUF) on equipment or structural supports.~~ Direct inspection methods are ~~inspection methods~~those conducted on the surface where damage is expected without the presence of a protective barrier (i.e. insulation or fireproofing system). Indirect inspection methods are inspection methods conducted with the protective barrier (i.e. the insulation or fireproofing system) still in place. ~~A discussion of all inspection methods is presented below along with the advantages and disadvantages of each method.~~

In addition, the inspection methods are classified as either quantitative, semi-quantitative, or qualitative depending on the type of measurement and scale for the results delivered. For purposes of this document, the following definitions apply:

a) Quantitative – A method or technique that quantifies the degree of surface material loss from corrosion by providing measured dimensional data values, i.e. X.XXX" (XX.Xmm) remaining wall thickness.

b) Semi-Quantitative – A method or technique that estimates the degree of surface material loss from corrosion by providing subjective interpretation-based data values put into estimated ranges, e.g. <25% wall loss, 25<50% wall loss, >50% wall loss.

~~a)~~c) Qualitative – A method or technique that assesses insulation/weather jacketing and fireproofing conditions that increase the likelihood of CUI/CUF being present.

~~7.1.8~~7.3.2 Direct Inspection Methods

~~7.1.8.1~~7.3.2.1 Visual Examination Method with ~~Complete~~ Removal of Insulation/Fireproofing

Visual examination of the metal surface is t~~T~~he most reliable quantitative method to detect thinning ~~CUI and CUF on~~of carbon and low alloy steel systems from CUI and CUF. The examination follows the~~is to physically~~ remov~~e~~al of~~the~~ insulation or fireproofing from the equipment and structure. CUI locations detected with visual examination typically require follow-up with other NDE techniques to quantify the damage. Often these areas are examined with a combination of UT, pit gauges, and structured light to determine wall loss and remaining wall thickness.

Note that any time removal of insulation and jacketing are performed to conduct CUI inspection, it is important to repair/replace the removed insulation and jacketing and ensure proper sealing of removed materials and/or watershedding of the jacketing to prevent further water ingress.~~and visually inspect the surface for damage.~~

The extent of insulation and fireproofing removal to expose the metal surface and the access to perform visual examination of those surfaces are key factors in the effectiveness of the examination to detect CUI and CUF. Complete insulation and fireproofing removal from equipment/structures and full access to visually examine the surface provides greater assurance of detecting general and localized corrosion than with partial removal of insulation/fireproofing or limited access to the surface. With partial removal of insulation and/or limited access to the surface to perform visual examination, the possibility of missing CUI/CUF damage increases.

Visual examination results obtained from removing insulation windows (i.e. holes cut in the insulation to expose the external surface for inspection) can help prioritize equipment for remediation or more comprehensive follow-up inspections. Windows should be cut where CUI is most likely to occur such as at poorly sealed insulation penetrations, at low points in the piping system where water can collect, at insulation support rings or vessel stiffening rings, or at areas where the insulation jacketing is in poor condition and water can penetrate the insulation system. The areas where insulation is removed should be large enough to be representative of the condition of the equipment. It may be necessary to cut several windows in suspect locations because of the difficulty in predicting where CUI damage may occur. For example, on a large drum or tower, it may be necessary to remove a vertical strip of insulation to represent different temperature zones in the equipment and to locate stiffener or insulation support rings. Once located, specific insulation support rings or stiffeners may then be selected for insulation removal around the circumference of the vessel to locate areas where degradation may be the most severe.

A variant of insulation windows is to perform visual examination at inspection ports in the insulation. This approach is of minimal value because of the limited amount of surface area exposed for inspection and the environment at the inspection port can be different than beneath undisturbed insulation.

Visual examination with insulation removal is often a follow-up activity to investigate suspect areas from external visual examinations and from other in-direct NDE techniques as well as to validate results from other NDE techniques.

Visual examination can be~~This approach is~~ costly since insulation or fireproofing on equipment or structural supports (i.e. I-beams, vessel skirts, etc.) has to be stripped and reinstalled. Scaffolding costs to access insulated areas being inspected can be significant especially for large vessels or piping systems on columns or towers. Scaffolding costs can be reduced in some situations utilizing rope access-qualified inspectors. Inspection personnel need to be careful to avoid contact with surfaces at or above 140 °F (60 °C).

Capabilities and limitations for visual examination are identified below.

~~1)~~ a) Capabilities

1) The only method that can both detect and quantify all corrosion damage of the surface exposed.

2) Photographic results and documentation are generally easily obtained.

b) Limitations

1) CUI damage can be missed if only a portion of the equipment is stripped and inspected;

2) Expensive because costs have to be incurred for removing and reinstalling insulation/fireproofing on equipment or structural components (note that additional costs are incurred if scaffolding is required to access insulated surfaces);

3) Special precautions are necessary on asbestos insulated systems;

4) Removal of insulation while the piping or equipment is in service may cause hot or cold spots, leading to a potential increase in internal corrosion or process issues;

5) Requires additional NDE follow-up to quantify metal loss and remaining thickness where CUI is identified

6) Windows cut in insulation pose a potential leak path for water ingress if insulation is not effectively repaired/sealed.

~~a) Advantages:~~

~~2) only method that can detect 100 % of all surface corrosion damage.~~

~~b) Disadvantages:~~

~~1) expensive because costs have to be incurred for removing and reinstalling insulation/fireproofing on equipment or structural components (note that additional costs are incurred if scaffolding is required to access insulated surfaces);~~

~~2) special precautions are necessary on asbestos insulated systems;~~

~~3) removal of insulation while the piping or equipment is in service may cause hot or cold spots, leading to a potential increase in internal corrosion or process issues;~~

~~4) personnel may be exposed to hot surfaces.~~

~~7.1.8.2~~7.3.2.2 Liquid Penetrant (PT) Examination Method

PT is a quantitative technique to detect surface breaking cracks, predominantly used for ECSCC of austenitic stainless steel. It relies on the capillary action of a liquid to flow into and subsequently out of a flaw. The surface being inspected is first cleaned to remove surface contaminants such as oil, water or other contaminants that could hinder the liquid penetrant from entering flaws. After cleaning the surface, a penetrant is applied and allowed to reside (dwell) on the surface for a prescribed amount of time to draw the liquid into the crack or other surface anomalies. Excess penetrant is later removed from the surface, and an absorbent, light-colored powder material (referred to as a developer) is applied over the inspection area. The developer acts as a blotter, drawing out any penetrant liquid present within cracks and other surface anomalies to the surface. As a result of the penetrant being drawn out, visible indications are produced allowing the inspector to assess the indications against the background of the developing powder. Figure 7 shows ECSCC detection with PT.

PT inspection is easily deployed for field applications. PT is typically performed between temperatures of 60*F and 120*F. Lower temperatures can be inspected by either heating of the part to the desired temperature or by qualifying the procedures at lower temperatures through practical demonstrations. Higher temperature can be inspected through the use of special high temperature penetrant materials.

Typically, ECSCC on insulated stainless-steel equipment is not normally detected until leakage occurs. When this occurs, inspection of the area using PT is an effective way of determining the extent of damage (i.e. cracking) on austenitic and duplex stainless steel. Damage is often associated with the weld heat affected zone.

Reports generally are provided by the technician with field sketch drawings and photos outlining inspection results and summaries.

Capabilities and limitations for liquid penetration ILI systems are identified below.

a) Capabilities
  1) Detects very small surface discontinuities.
  2) Can detect ECSSC on stainless steel equipment.
  3) PT is easy to deploy and highly portable.
b) Limitations
  1) Geometry (rough surfaces) can impact inspection results through heightened background where the penetrant can be trapped and difficult to thoroughly clean.
  2) Requires access to the same side surface of the equipment being inspected.

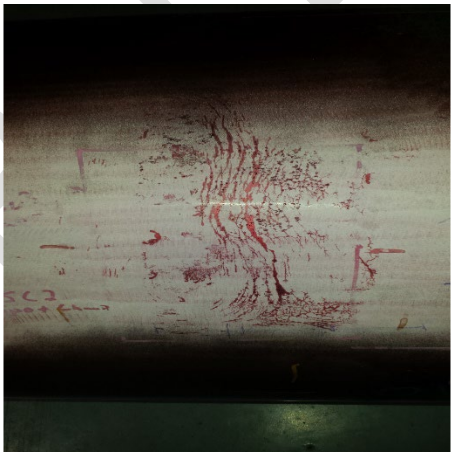


Figure 7~~:~~ - Two examples of ECSCC detected with PT

~~Typically, ECSCC on insulated stainless steel equipment is not normally detected until leakage occurs. When this occurs, inspection of the area using liquid penetrant examination method (PT) is an effective way of determining the extent of damage (i.e. cracking) on austenitic and duplex stainless steel. Damage is often associated with the weld heat affected zone.~~

~~Liquid penetrant examination is generally limited to surface temperatures below 120 °F (49 °C). After cleaning of the surface being inspected, the penetrant is applied and allowed to reside on the surface for a period of time for capillary action to draw the liquid into the crack. Excess penetrant is then removed from the surface and dried, and an absorbent, light-colored powdered material (referred to as a developer) is applied over the inspection area. The developer acts as a blotter, drawing any penetrant liquid present within cracks to the surface. As a result of the penetrant being drawn out, visible discolored streaks are produced plainly delineating the cracks. The inspector then can observe the indications against the background of the developing powder.~~

~~Advantages and disadvantages of liquid penetrant inspection with partial insulation removal or at inspection ports are as follows.~~

~~a) Advantages:~~

  ~~1) capable of detecting very small discontinuities;~~

  ~~2) relatively inexpensive nonsophisticated equipment.~~

~~b) Disadvantages:~~

  ~~1) surfaces have to be clean and free of organic or inorganic contaminants that can impede the action of the penetrating media;~~

  ~~2) when sprayed, penetrants are easy to ignite when exposed to ignition sources;~~

  ~~3) cold surfaces require longer dwell times to allow sufficient time for penetrant to be drawn into the crack.~~

7.3.2.3 Surface Eddy Current (SEC)

SEC examination is a quantitative technique based on electromagnetic induction principles for detection of cracking and other surface anomalies. Conventional SEC is an amplitude-based and phase technique that relies on inducing electrical currents into a material that is being inspected and observing the interaction between those currents and the material without the use of chemicals or couplant. Eddy currents are generated in conductive material, ferrous or non-ferrous, by means of electromagnetic coils in a test probe. The eddy currents are monitored by measuring the probe coils electrical impedance changes which allows for the characterization and quantification of indications within the material. SEC uses the electrical properties of a material to assist in determining the mechanical integrity of what is being examined. This inspection technique is performed manually at scan speeds of 3~~"~~ in. (7.6 cm) to 6~~"~~ in. (15.2 cm) per second.

Surface eddy current array (SECA) uses several individual coils grouped together in one probe assembly including digital displays to show phase or amplitude changes providing detection and orientation mapping of surface anomalies. Multiple coils are arranged in a row which allows the inspection to cover a larger area with a single pass of the probe. This inspection technique may be performed manually at scan speeds of 3~~"~~ in. (7.6cm) to greater than 12~~"~~ in. (30.5cm) per second, depending on the application and the frequencies being utilized. Encoders may also be used with SECA probes to provide dimensional details (position and sizing) from the images and data collected.

SEC can detect surface-breaking cracks, such as ECSSC of stainless steel and IGSCC of carbon steels, that may have been initiated by CUI. SEC is primarily used as a detection tool, however with the proper use of calibration standards containing EDM notches at various depths, depth sizing is possible. Accordingly, SEC can provide a measurement of the depth, volume, and length of an indication in the material being inspected. Depth sizing can be measured to a maximum depth of 0.200~~"~~ in. (5 mm). There is a low probability of detection of cracks measuring less than 0.020 in.~~"~~ (0.5 mm) depth and 0.080 in.~~"~~ (2 mm) in length. Typically, crack depths are classified into 3 categories: Less than 0.040 in.~~"~~ (1 mm), 0.040 in.~~"~~ (1 mm) to 0.080 in.~~"~~ (2 mm), and greater than 0.080 in.~~"~~ (2 mm).

SECA instrumentation can be battery powered and portable. Probe housings can be designed to allow attachment of wheels or fixtures for a smoother and consistent movement across the surface areas. Array probe data can be recorded, allowing the data to be reviewed after the scans have been completed, and provide C-scans and 3D imagery whereas conventional probe data may be recorded only as screenshots. This makes the SECA technique less operator dependent than the conventional one.

Little to no surface preparation is required to perform SEC inspections. Typically, a wire brush or other means of removing loose scale or debris is all that is needed. Moist or damp surfaces will not interfere with the inspection. It is best if the welds are buffed smoothly as the geometry, excessive weld spatter, scale, rust, or loose paint can negatively influence the data.

SEC can be performed without removing any existing non-conductive coatings of uniform thickness provided coatings are less than 3 mils (0.08 mm). A calibration standard with the same lift-off variable will need to be utilized to properly size any detectable indications.

Both conventional and array techniques are more efficiently performed with two people. This is typically done with a Level II Eddy Current technician with analysis experience and an assistant. The time to perform the examinations will depend on the surface area or ~~linerar~~linear footage of weld being examined and the size of the probe(s) being used. Though SECA is less operator dependent, the analysis of the data may require higher levels of experience and training since the setup and calibration can sometimes be complex.

Reference standards are required for proper SEC examination, including the use of like materials (i.e. Type 304SS reference standards should not be used on Typ~~p~~e 347SS components). The width of the EDM notch on the reference standards influences the detection and sizing thresholds for any cracks found in the material being inspected. Even though the calibration standard notches have very small widths, stress corrosion cracks may be even tighter. When using conventional SEC sizing, these tighter cracks may be under-called by the technician. Additionally, any cracks that are at or near the sizing limit of 0.200 in.~~"~~ (5 mm) should be ground out or verified by alternative NDE (e.g. UT) to verify the true depth is not greater than the 0.200 in.~~"~~ (5 mm) limit.

SEC examinations should include detailed reporting including but not limited to the instrument settings, calibration information, photos of the areas inspected, and data graphics and/or details of any indications detected. Data recorded with eddy current array inspection can be provided when requested. Owner-operators should verify SEC results with complementary NDE techniques such as PT, or MT.

Capabilities and limitations for SEC are identified below.

a) Capabilities
  1) Both the array and conventional techniques have multi-directional probes that have sensitivity to environmental stress corrosion cracking, e.g. ECSCC and IGSCC, in any orientation.
  2) Can be performed on welds or base metal of all equipment types.
  3) Flexible probe designs can conform to various geometries and provide increased scan coverage. Flexible probes allow for minimal lift-off of the coils to the material.
  4) Large test areas can be gridded out or sectioned to ensure full inspection coverage with areas of

overlapping scans.

5) Inspections performed on nozzles or other welded connections should utilize a conventional eddy current probe.

b) Limitations
   1) Typically, the probes are designed to function on materials that are ambient temperature. High temperature surface eddy current array probes are available for temperatures up to 300° F (149° C), while specialty eddy current probes may be available for higher temperatures up to 700° F (370° C)
   2) SEC has a limited depth of penetration, and cracks need to be surface breaking to confidently be detected.
   3) The probe size can be inadequate for larger surface areas and multiple manual scans may be required for 100% coverage.
   4) SEC cannot typically be utilized on materials that contain thin conductive coatings, such as TSA.
   5) Changes in geometry or chemical/metallurgical changes in the material can negatively influence the SEC examination and inspection results.

~~7.1.9~~7.3.3 Indirect Inspection Methods

~~7.1.9.1 General~~

~~Indirect inspection methods can be classified as semi-quantitative methods that attempt to estimate the relative degree of surface corrosion damage present or as qualitative methods that attempt to look for the impact that surface corrosion damage has on the insulation/fireproofed system.~~

~~7.1.9.2 Semi-quantitative Methods~~

~~7.3.3.2.1 General~~

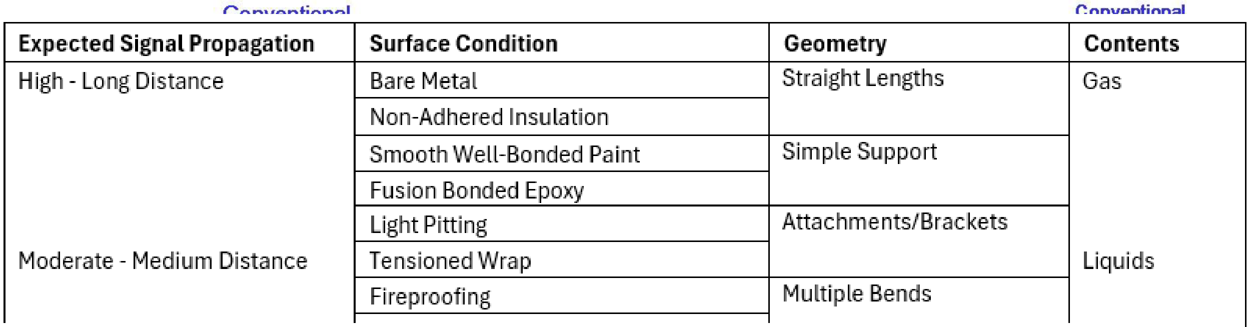
~~These are inspection methods that indirectly quantify the relative degree of surface corrosion that has occurred. These methods are conducted without complete removal of the insulation or fireproofing from the equipment or structural support and include ultrasonic, radiographic, eddy current, or thermal inspection methods.~~

~~7.1.9.3~~7.3.3.1 ~~7.3.3.2.2~~ Guided Wave Testing (GWT) Examination Method

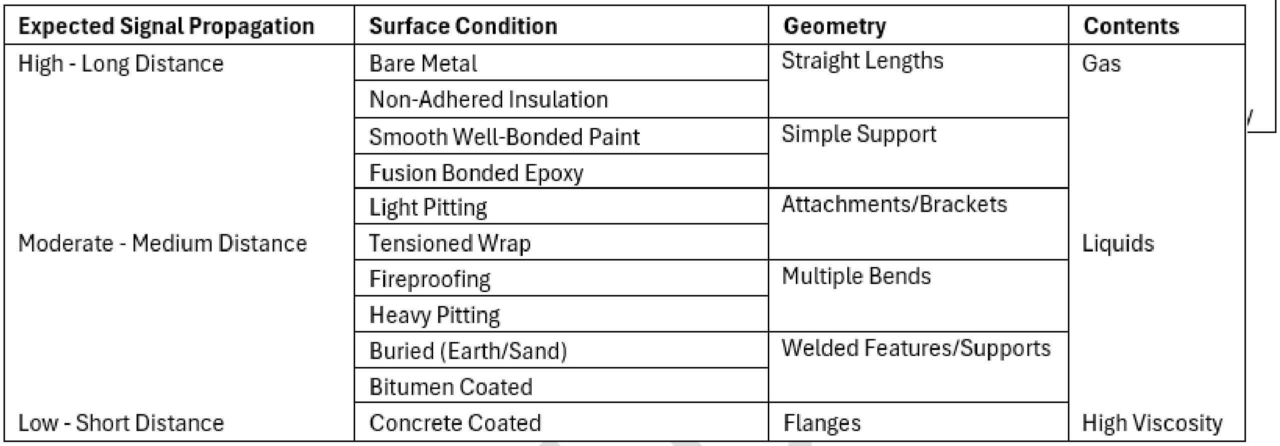
Guided ~~W~~wave, also referred to as ~~L~~long ~~R~~range ~~U~~ultrasonics, is a semi-quantitative pulse-echo ultrasonic technique. From a chosen inspection point, a ring of transducers is affixed around the circumference of a pipe, introducing a uniform wave front of torsional, and/or longitudinal waves in both a downstream and upstream direction from a single test point location.

Guided waves can propagate varying distances along the pipe, from a few yards/meters to several tens of yards/meters depending on test conditions and attributes. Some of these attributes include pipe diameter, material thickness, material type, material temperature, surface conditions including internal and external coatings, internal or external wall loss, internal process fluid, supports, contact with external items, and fittings. Table 19 lists the influence of some key test attributes on signal propagation.

As compared to many other types of ultrasonics, where the readings obtained relate to the area just under the transducer, GWT encompasses the full area of the pipe body down the length of the inspection coverage, providing for large area, long distance screening. Figure 8 illustrates the difference between manual UT and GWT.



Expected Signal Propagation	Surface Condition	Geometry	Contents
High - Long Distance	Bare Metal	Straight Lengths	Gas
	Non-Adhered Insulation		
	Smooth Well-Bonded Paint	Simple Support	
	Fusion Bonded Epoxy		
	Light Pitting	Attachments/Brackets	
Moderate - Medium Distance	Tensioned Wrap		Liquids
	Fireproofing	Multiple Bends	



Expected Signal Propagation	Surface Condition	Geometry	Contents
High - Long Distance	Bare Metal	Straight Lengths	Gas
	Non-Adhered Insulation		
	Smooth Well-Bonded Paint	Simple Support	
	Fusion Bonded Epoxy		
	Light Pitting	Attachments/Brackets	
Moderate - Medium Distance	Tensioned Wrap		Liquids
	Fireproofing	Multiple Bends	
	Heavy Pitting		
	Buried (Earth/Sand)	Welded Features/Supports	
	Bitumen Coated		
Low - Short Distance	Concrete Coated	Flanges	High Viscosity

Figure 8~~:~~ - Principle of Guided Wave UT Compared with Conventional Manual UT

GWT can be used to detect CUI as it is capable of detecting both internal and external corrosion, and in some cases, substantial general/ isolated pitting, and circumferential cracking. The minimum detection threshold is generally considered a 5% change in cross sectional area; however, with recent improvements in signal processing and guided wave technology, smaller defects can many times be observed depending on overall test signal-to-noise ratio. Minimum detection thresholds are largely impacted by system attributes and should be evaluated on a case-by-case basis.

GWT requires direct contact with the pipe body to be inspected. For insulated piping, most equipment manufacturers require a minimum of 12” (300mm) axially with a radial clearance of 3” (75mm). GWT requires minimal surface prep at each test location. The test surface should be clean and free of foreign debris, such as dirt, rust, scale, and loose or damaged coating. Well adhered coating and epoxy layers up to an approximate 0.04” (1.0mm) do not require removal.

Table 19: System attributes effect on signal propagation

Under general testing conditions, a typical guided wave crew may consist of 2 or 3 people; however, this may change depending upon the project. Typical setup and collection times can range from 10 – 30 minutes per test location.

Coverage with GWT is better with piping systems conducive to the transmission of ultrasonic signals, consisting of long lengths of pipe, with minimal bends or welded features. When the piping system contains multiple fittings, changes in direction, or welded features, additional test points may be required to ensure proper coverage at an acceptable sensitivity level. In general, it is advisable to only inspect through one change in direction up to the second change in direction prior to initiating another test location. Further, GWT will not pass through mechanical connections such as flanges, valves, and other similar items.

Owner-operators should confirm GWT operators have proper training, certification, and qualifications consistent with the manufacturer’s recommendations and training schemes. Additionally, wave mode selection is paramount, with the torsional wave mode being the most widely used. Grading criteria for a given system should also be defined or agreed upon prior to executing a project. As with many other available NDT and inspection techniques, equipment calibration or verification is needed, and includes the software versions being used. While many other factors need to be considered, training/certification, test protocol, grading criteria, and the use of calibrated or manufacturer verified equipment is important.

GWT techniques provide an overall screening of the system under test, identifying pertinent features and potential damage alike. To properly survey the results, it is best to visually survey and confirm findings from the recorded Guided Wave trace to the actual pipe under test. Any remaining items not able to be visually verified typically have additional follow-up inspections/verification.

In the example shown in Figure 9, from the test position, an inspected range of greater than 220 ft (67 m) was achieved. All welds are clearly identified along with a single support, however, moving to the right within the trace, a large response is noted, being estimated by the system as a 23% change in cross-sectional area, requiring additional quantitative follow up.

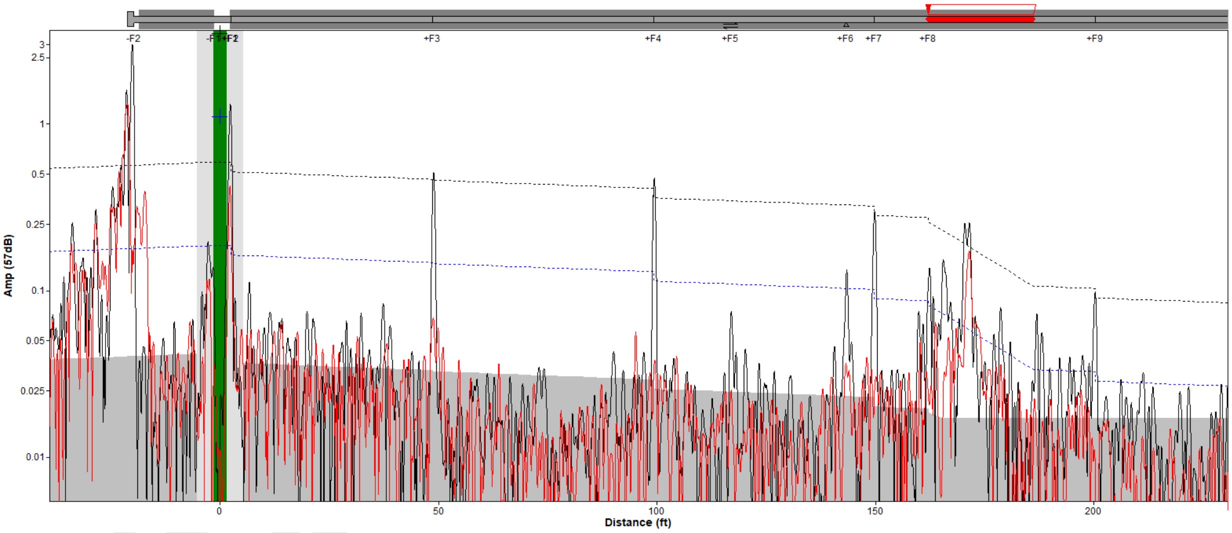


Figure 9: Example output from a GWT inspection

Other system and data checks are available within a given manufacturer’s software, including an itemized list of findings, test location details, system details, signal to noise ratios, system user, software versions, among other items.

Capabilities and limitations for GWT are identified below.

a) Capabilities
    1) Examines 100% of the pipe wall volume at extended lengths.
    2) Capable of identifying damage or cross-sectional changes of more than 5%, emanating from both the internal and external surfaces of the pipe under test.
    3) Provides accurate location details, including GPS/GIS coordinates, and circumferential position (e.g. reflector at the 6 o’clock position) for additional follow up outside the immediate test location.

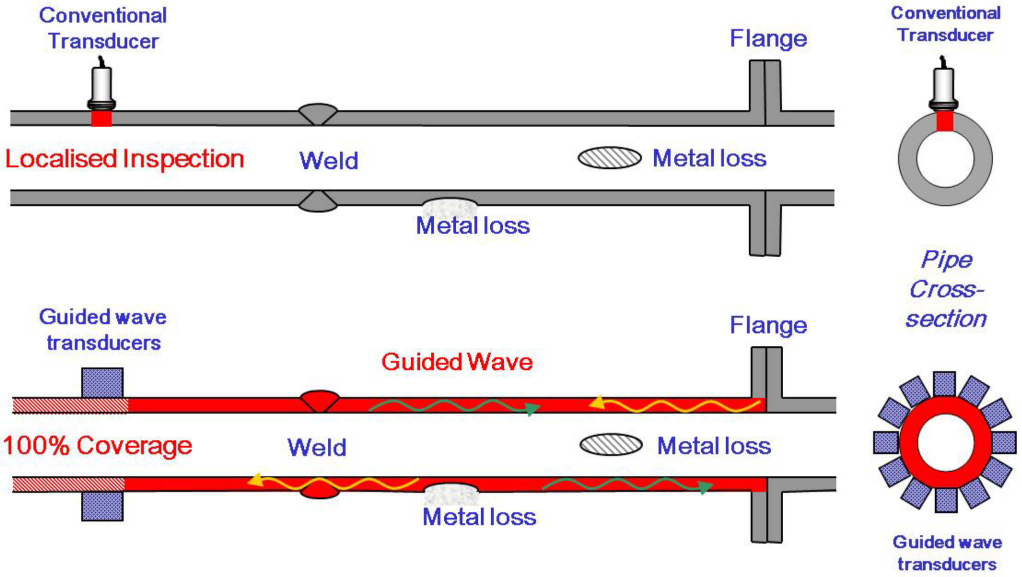
    4) High temperature deployments available up to 660F (350C).
    5) Standard diameters available from 1.5” to 78”
    6) Real-time processing and evaluations of results.
    7) High reproducibility of results (this item may be further enhanced by use of permanently mounted sensors, as shown in Figure 10, measuring small changes over time).

b) Limitations
    1) Changes in direction and fittings attenuate signal, reducing inspected lengths and reducing the overall test sensitivity.
    2) Breaks in pipe continuity, such as flanged joints, valves and large branch connections (i.e. >1/2 diameter of main line), become the end points of any test location.
    3) Difficult to assess damage occurring within fittings, such as 1D elbows.
    4) Unable to detect cracks running along the axis of the pipe and limited detection of isolated pitting/corrosion with less than 5% cross-sectional change.
    5) Internal and external coatings, other than FBE or paint, may create highly attenuative circumstances, resulting in reduced axial coverage from a single inspection location.
    6) Piping systems in direct contact with the ground may experience higher than average attenuation, resulting in reduced coverage from a single test location.
    7) High frequency external noise may create errors within the collection protocol, reducing or limiting inspection effectiveness.
    8) Results obtained by use of GWT alone are not suitable for remaining life evaluations without additional quantitative follow-up.

Figure 10: ~~9—~~Permanently Installed Monitoring Array of Transducers ~~(courtesy of Guided Ultrasonics Ltd.)~~

~~Guided wave testing (GWT) (also referred to as “long range ultrasonic testing”) can be used to detect CUI on piping. This testing can be performed without the requirement of extensive insulation removal. It can also provide inspection coverage over long distances under the right circumstances. GWT utilizes an array of low-frequency ultrasonic transducers, attached to the pipe circumference of a pipe, to generate an axially symmetric wave in both directions away from the transducer array.~~

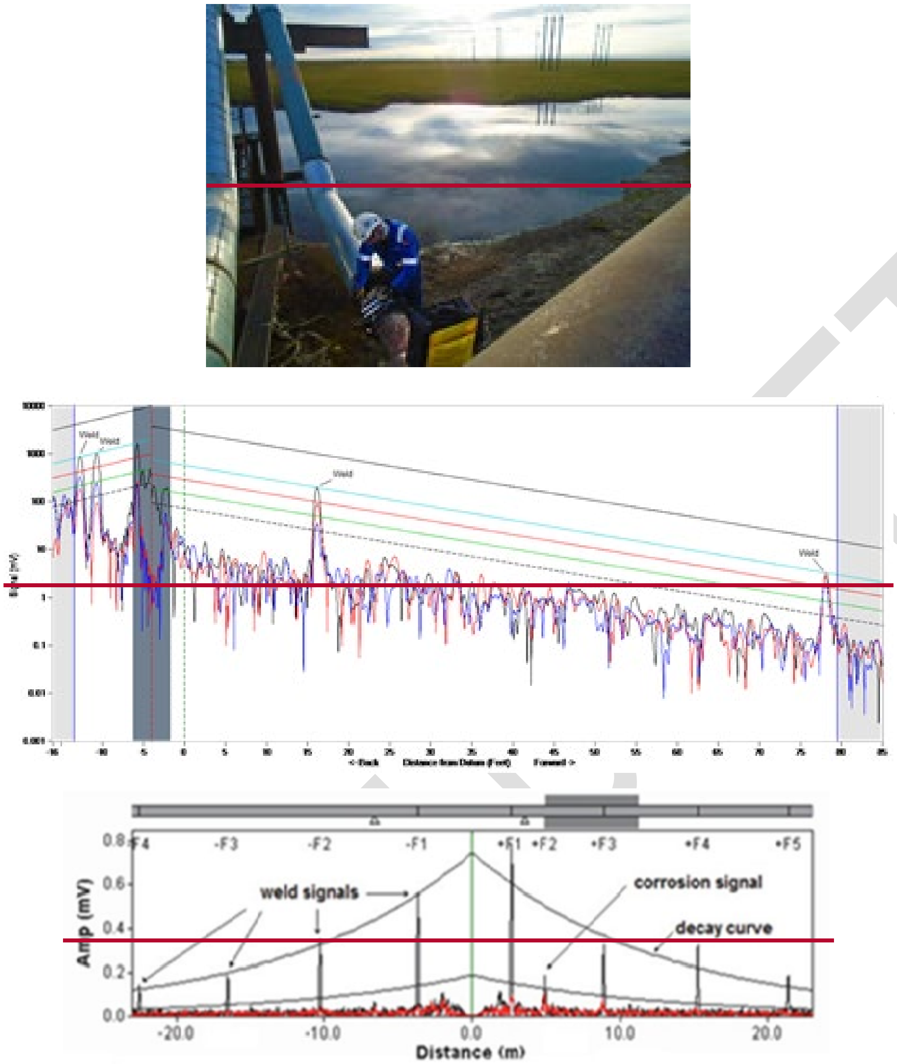
~~It is a pulse-echo system aimed at screening large volumes of material, usually piping, from a single test point (see Figure 6). Its initial design and application was for detecting CUI in petrochemical plant pipe-work, but it has found widespread use in other inspection situations where pipes or tubes are not easily accessible, for example where they encased in a sleeve or elevated above the ground. Guided wave equipment can use both longitudinal and torsional wave modes to transmit the signal. Both modes are commonly used; however, for attenuative applications the torsional wave mode is more desirable.~~



~~**Figure 6—Principle of Guided Wave UT Compared with Conventional Manual UT**~~

~~The aim of the inspection is to rapidly test long lengths of pipe, without extensive insulation removal, achieving 100 % coverage of the pipe wall and to identify areas of corrosion for further evaluation using other nondestructive testing techniques. The technique is equally sensitive to metal loss on both the outside and inside surfaces of the pipe.~~

~~Figure 7 shows examples of guided wave equipment and signal displays.~~



~~Figure 7—Guided Wave Transducer Arrays, Signal Representation, and Results~~

~~The factors affecting the performance of guided waves tool and the test range that can be achieved are summarized in Figure 8.~~

~~Advantages and disadvantages for GWT are shown below.~~

~~a) Advantages:~~

  ~~1) can detect internal and external corrosion, cost- and time-efficient screening technique;~~

  ~~2) can inspect long lengths of pipes (hundreds of feet in ideal conditions) within minutes in each direction away from the transducer array;~~

  ~~3) GWT technique is utilized to inspect inaccessible areas such as buried or coated pipes;~~

  ~~4) minimum insulation (~3 ft) needs to be removed at the tool location;~~

~~5) pipe sizes from 1.5 in. to 78 NPS can be tested.~~

~~b) Disadvantages:~~

~~1) screening tool;~~

~~2) relatively low resolution and low sensitivity;~~

~~3) limited to applications operating between −40 °F to 932 °F;~~

~~4) piping containing high-viscosity liquids, heavy external coatings, buried piping, or piping with an excessive number of welds/fittings will reduce the extent of inspection coverage;~~

~~5) isolated pitting or corrosion in the immediate vicinity of welds may not be detected;~~

~~technique is operator dependent.~~

7.3.3.2 ~~7.3.3.2.3~~ Radiographic Examination Methods

7.3.3.2.1 General

There are various techniques involving radiographic methods that can be used to detect CUI damage. Radiography is efficient and effective: it minimizes removing and replacing insulation. Radiography essentially requires a source of radiation opposite a detection medium that records the radiation either as a film or digital image. These include profile radiography, density radiography, film, computed and digital radiography, real-time radiography, flash radiography, radiometric profiling.

In service prone to CUI, profile radiography identifies corrosion damage in insulated piping. It does not identify cracks such as ECSCC on austenitic or duplex stainless steel.

7.3.3.2.2 Principles of Profile Radiography

Profile radiography is typically a manual, quantitative technique used to radiograph a small section of the pipe wall to assess remaining wall thickness. Radiography requires a radioactive source opposite to a film or digital image detection system recording the radiation received after interacting with sections of the pipe wall. A comparator ball of known size is used to ~~assess~~ determine the pipe ~~remaining~~ wall thickness ~~of the pipe~~ on the radiographic image~~(see Figure 10)~~. The exposure source is ~~usually~~ often iridium 192, with cobalt 60 being used for heavier wall piping but ~~. Alternately, profile radiography~~ can also be done using X-ray sources. The image detection system can be conventional film, an imaging plate for computed radiography and a flat panel detector for DDA radiography. Profile radiographs can be taken using either a tangential or double-wall radiographic technique. Figure 11 illustrates a tangential and double-wall setup using imaging plates.

Profile radiography is an effective pipe evaluation method for general thinning and localized corrosion from CUI/CUI without insulation removal. However, ~~Q~~quantitative results can only be provided for relatively small areas so localized corrosion could be missed.~~.~~ This technique is not capable of detecting ECSCC on austenitic or duplex stainless steels. Profile radiography can generally be performed on piping up to 8” (152 mm) .~~but becomes technically challenging in p~~However, piping systems over 8 in. ~~-~~(152.4 mm)~~;~~ and those of heavier wall thicknesses becomes technically challenging and~~however, this~~ is dependent on radiation energy level and the type of product inside the piping. ~~Quantitative results can only be provided for relatively small areas. Profile radiographs can be taken using either a tangential or double-wall radiographic technique.~~

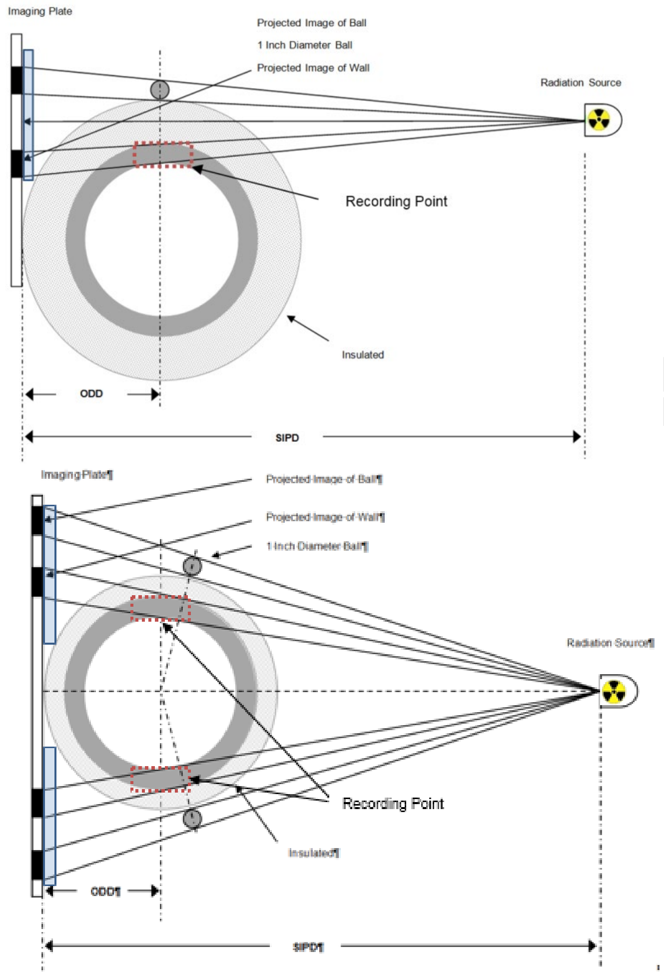


Figure 11~~6~~~~10~~—Schematic of Profile Radiography Setup

~~This technique is not capable of detecting ECSCC on austenitic or duplex stainless steels.~~ ~~In addition, radiation safety can be a safety concern.~~ In addition, safety and radiation alarms that become active need to be considered. The need to cordon off a large area for radiographic examination can result in downtime and personnel scheduling conflicts. ~~Profile radiography is usually preferred to assess insulated piping for uniform corrosion damage.~~ Figure 12 ~~11~~ shows two examples of profile radiography images.

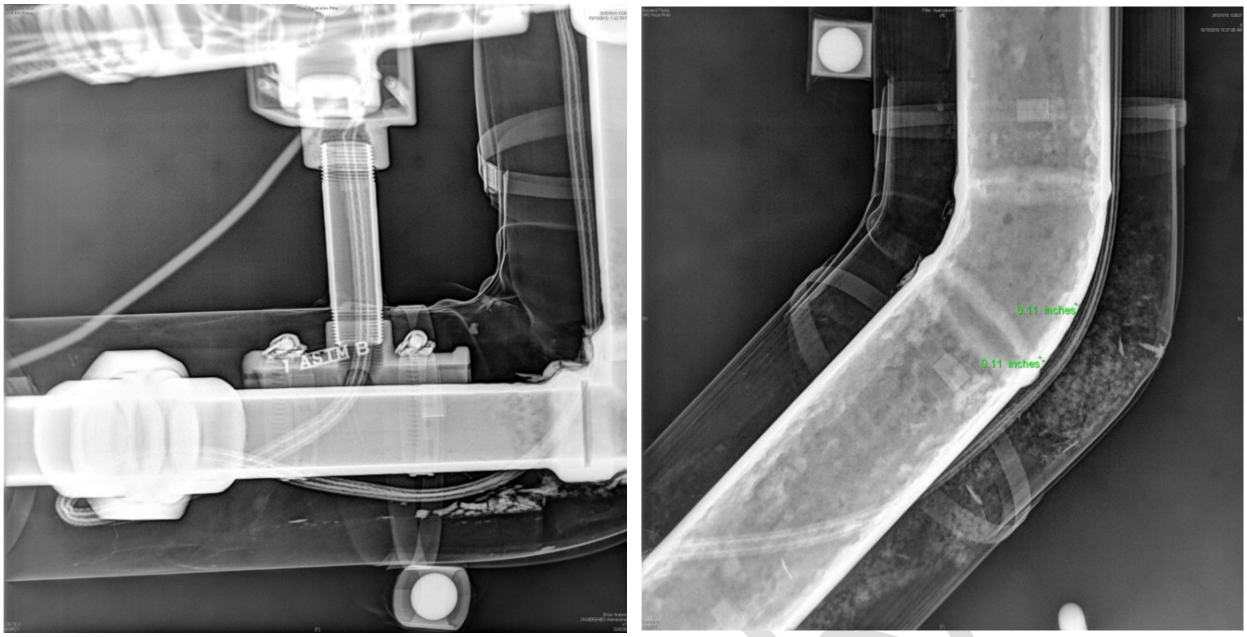
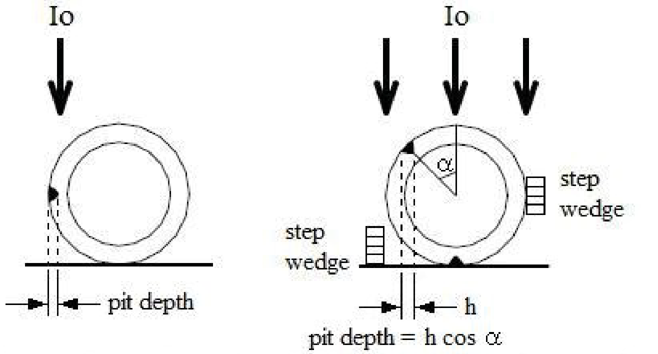
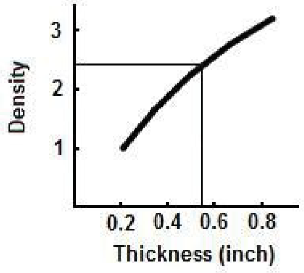


Figure ~~11~~12—Examples of Profile Radiograph Showing CUI Damage on an Insulated Pipe ~~(images courtesy of Acuren)~~

~~When pitting damage is perpendicular to the axis of the radiographic beam, the pit depth measurement can possibly be measured directly off the radiograph provided the pit dimension is of a sufficient size to be viewed in the radiographic image [see Figure 12 a)]. When the pitting is located at some angle to the axis of the radiographic beam, the projected pit depth (*h*) requires geometric correction as detailed in Figure 12 b).~~ Guidelines on the application limits for profile radiography are shown in Figure 13.

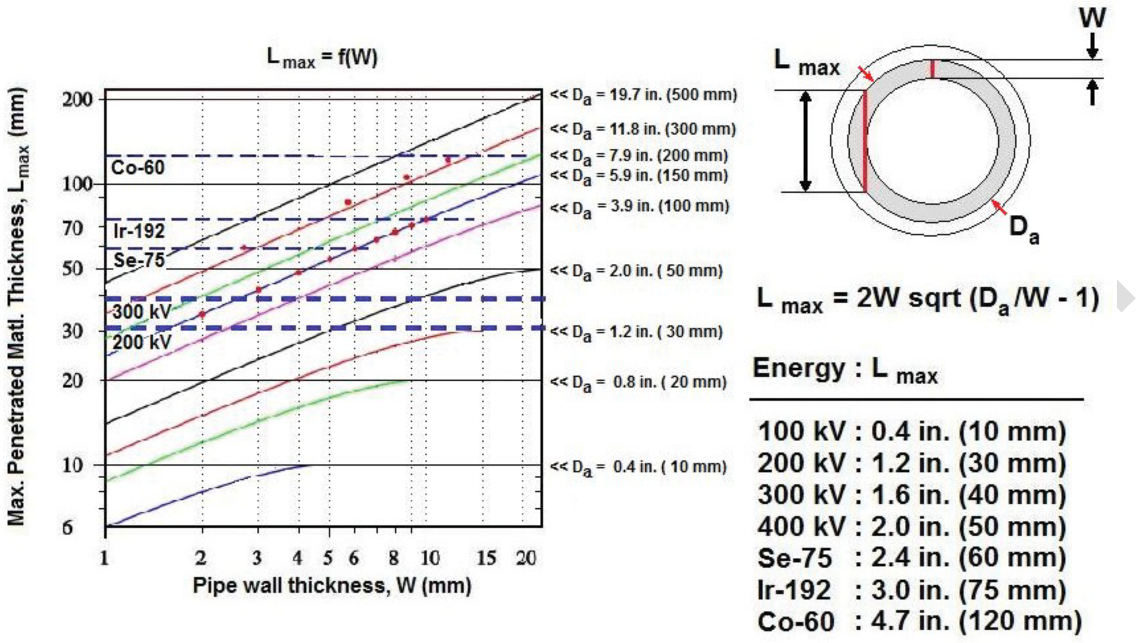


a) Pit perpendicular to beam axis b) Pit not perpendicular to beam axis



c) Density/Thickness curve

~~Figure 12—Pit Depth Measurement Techniques~~



$L_{max} = 2W \, \mathrm{sqrt}(D_a/W - 1)$

Energy	: L_{max}
100 kV	: 0.4 in. (10 mm)
200 kV	: 1.2 in. (30 mm)
300 kV	: 1.6 in. (40 mm)
400 kV	: 2.0 in. (50 mm)
Se-75	: 2.4 in. (60 mm)
Ir-192	: 3.0 in. (75 mm)
Co-60	: 4.7 in. (120 mm)

Figure 13~~713~~—Application Limits for Tangential and Film Density Radiography

Profile radiography can be used as an initial inspection technique to identify the presence of CUI, particularly on small bore piping, but is often used as a follow-up to suspect areas from other NDE screening examinations. Refer to ISO 20769-1 ~~Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays — Part 1: Tangential radiographic inspection,~~ for additional information in performing profile radiography.

Capabilities and limitations for profile radiography are identified below.

a) Capabilities
   1) Ability to measure pipe wall thickness in the plane of exposure.
   2) Techniques can detect/image gross corrosion to improve overall CUI detection.
   3) Can inspect piping in-service, with or without product.

b) Limitations
   1) Generally, it is more difficult to perform on pipe diameters greater than 8 in. (152 mm) and heavier wall thicknesses.
   2) Size and morphology of the corrosion is a significant factor in the ability to measure the thinnest point. Additional profile shots may be necessary to have confidence that the thinnest point is measured.
   3) Requires consideration of radiation safety.
   4) In-service piping vibration can distort image definition.

~~The advantages and disadvantages of profile radiography are as follows.~~

~~a) Advantages:~~

  ~~1) exposes a small section of pipe to tangential radiation and compares the image dimensions with that of a comparator of known size, thereby giving a fairly accurate wall thickness measurement;~~

  ~~2) used routinely on piping 1 NPS and above;~~

  ~~3) can rapidly detect/image gross corrosion that improves overall detection capability for CUI;~~

  ~~4) ability to inspect piping and ancillary components without the modification or removal of insulation;~~

  ~~5) capable of inspecting piping and components “in service,” with or without product.~~

~~b) Disadvantages:~~

  ~~1) limitations on pipe size that can be inspected [outside diameter (OD) and wall thickness], with other limitations being source strength (isotope and/or X-ray tubes);~~

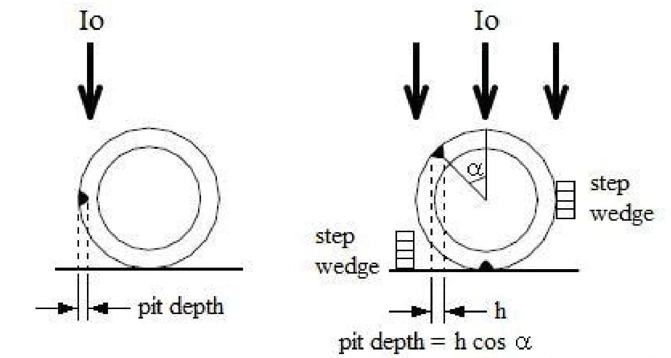
  ~~2) radiation safety considerations;~~

  ~~3) in-service considerations such as pipe vibrations can distort image definition.~~

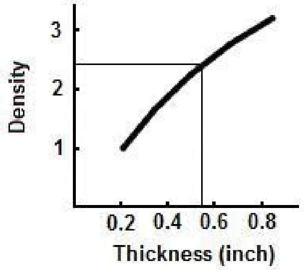
7.3.3.2.3 Principles of “Film Density” Radiography

“Film density” radiography is a manual semi-quantitative technique based upon changes in film density or digital image grey level. Variations in thickness of a component being examined results in different radiation intensities being captured on the film/detector from the radiation source. The method can estimate the change in thickness between locations on the radiographic image. Film density can be used to detect CUI-related corrosion loss and estimate wall thickness from a density variance between locations using a logarithmic calculation. Gray level changes in digital images are typically directly proportional to component thickness change allowing for simpler calculation and use of software to enhance results and accuracy.

Profile radiography and “film density” radiography are complementary methods. The double wall radiographic technique has a similar set up to double wall profile radiography. However, instead of a comparative ball, a step wedge(s), made from material that is radiographically similar to the piping being evaluated, is used to develop a density/thickness reference curve. The step wedge has multiple steps of known thickness. An example of how profile radiography and “film density radiography compliments each other is pitting damage. When pitting damage is perpendicular to the axis of the radiographic beam, the pit depth measurement can possibly be measured directly off the radiograph provided the pit dimension is of a sufficient size to be viewed in the radiographic image [see Figure ~~12~~14 a)]. When the pitting is located at some angle to the axis of the radiographic beam, the projected pit depth (h) requires geometric correction as detailed in Figure ~~12~~14 b).



a) Pit perpendicular to beam axis   b) Pit not perpendicular to beam axis



c) Density/Thickness curve

Figure 14: Pit Depth Measurement Techniques

"Film density" radiography only measures the average wall thickness (AWT) of the piping and is commonly used on piping 12 in. (305 mm) or below; however, with some trade-offs, this technique can be used on larger diameter piping. Multiple exposures are typically needed to obtain full circumferential coverage. The accuracy of the image becomes limited by the increase in metal thickness associated with the pipe curvature that the radiation penetrates. The number of exposures is determined by the source to pipe center distance, pipe diameter and pipe wall thickness.

The appropriate energy and film speed should be chosen when the film density measurement technique is utilized to achieve good image quality. It is important to locate the pit or local corrosion area correctly. Most accurate results can be obtained with the pitting/localized corrosion area centered on the film/detector. In addition, the pitting/ should lie on the film/detector side during exposure to prevent an underestimation of its depth. The depth of the pitting and remaining wall thickness can be determined using the measured density of the pit and sound wall and a density/thickness reference curve, as shown in Figure 14 c.

Refer to ISO 20769-2 ~~Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays — Part 2: Double wall radiographic inspection,~~ for additional information on performing density radiography.

Capabilities and limitations for film density radiography are identified below.

a) Capabilities

1) Technique can locate irregular or scattered pits;
2) Provides a permanent record of examined areas;
3) Provides a relatively easy scanning method without the need for insulation removal.

b) Limitations

1) Corrosion products/scale can decrease film density and result in an underestimate of the wall

thickness;

2) Liquids present in the equipment (piping) will reduce the transmitted radiation;
3) An ultrasonic examination will also be required if density curves are not calculated~~.~~;
4) Piping or equipment would require insulation to protect the film at elevated temperatures.

7.3.3.2.4 Conventional Film

Film RT is the dominant, volumetric nondestructive testing technique. Film is lightweight, flexible, and used in a variety of applications. Film processing requires a significant amount of time to develop radiographs (~20 min), specialized facilities for film processing (i.e. a dark room), and generates hazardous wastes that require disposal (namely, silver thiosulfate).

Film RT was used commonly for profile and film density radiography prior to the availability of DDA panels and CR plates. Today, increased exposure times, increased film processing time, and a lack of film evaluation software tools limit the use and effectiveness of film for CUI radiographic examinations. However, film RT is still commonly used to perform volumetric non-destructive testing of as-fabricated pressure and structural equipment.

Film RT can detect general corrosion/wall loss in piping. However, the images typically have less resolution than DDA and CR images. The minimum detection threshold depends on the insulation thickness, type, and jacketing type being penetrated.

Film images are stored. However, film radiographs have a limited shelf life and need a temperature- and humidity-controlled storage environment.

Capabilities and limitations for conventional film RT are identified below.

a) Capabilities
   1) Film can detect general corrosion/wall loss and isolated scabs.

b) Limitations
   1) Radiation exposure time is typically longer than for DDA and CR.
   2) The image does not typically show the multiple components (valves, pipe, fittings, and threaded parts) in the same image. DDA and CR have more latitude.

7.3.3.2.5 Computed Radiography (CR)

CR [photostimulable luminescence (PSL) method] has a two-step radiographic imaging process. First, radiation penetrates a storage phosphor imaging plate; second, the luminescence from the imaging plate's photostimulable luminescent phosphor is stimulated, detected, digitized, and displayed on an image display monitor. Spatial resolution with CR can be as 25um and lower with some systems. This process takes several minutes to produce images, and the imaging plates can be reused.

CR detects both internal and external general corrosion, localized corrosion and pitting, corrosion, and waterlogged insulation. The minimum detection threshold depends on the diameter, insulation thickness, type, and insulation jacketing type. Predominantly manual mode of delivery although crawlers may be available.

CR images are digital images. They can be stored, emailed, and processed on a computer.

Capabilities and limitations for CR are identified below.

a) Capabilities

1) Can detect general corrosion/wall loss and isolated scabs.
2) Provided the various diameters allow, CR images can show multiple components (valves, pipe, fittings, and threaded parts) in the same image.
3) Typically performed while the equipment is in-service.
4) Requires less radiation to produce an image compared to film radiography.
5) CR images do not require film and chemicals– as required to process film.
6) Requires fewer retakes than film due to underexposure or overexposure.
7) CR plates are more durable than DDA panels.

b) Limitations

1) CR's typical operating temperatures are −4 °F to 122 °F (−20 °C to 50 °C). For storage, a broader range is acceptable, −40 °F to 158 °F (−40 °C to 70 °C). The operating humidity should range from 10 % to 90 %.

7.3.3.2.6 Digital Detector Array (DDA)

DDA systems convert ionizing or penetrating radiation into a discrete array of analog signals. These are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted upon the input region of the device. The following technologies are used in direct digital imaging systems:

— amorphous silicon devices – the main devices in DDA for CUI,
— charge-coupled devices, and
— complementary metal oxide semiconductor devices.

Digital systems allow viewing and analysis in seconds allowing the technician to view results in the field. The increased processing speed is a result of the unique construction of the pixels in a digital system. While DDAs may have a lower spatial resolution than CR, typically between 50-200um range, DDAs can provide superior contrast resolution, by using frame averaging, to CR and most film applications.

DDA detects both internal and external general corrosion, localized corrosion and pitting, and waterlogged insulation. The minimum detection threshold depends on the diameter, insulation thickness, type, and the insulation jacketing type.

DDA software analyzes the image, minimizing and mitigating an inspector's subjective assessment. Specialized software reports remaining thickness evaluations around the pipe circumference (not limited to areas exposed tangentially).

The images are stored, emailed, or processed on a computer. Newer processing software can assess material losses and pit depths in areas other than the tangent.

Capabilities and limitations for DDA are identified below.

a) Capabilities
1) Can detect general corrosion/wall loss and isolated scabs.
2) Provided the various diameters allow, DDA images show multiple components (valves, pipe, fittings, and threaded parts) in the same image.
3) Typically performed while the equipment is online.
4) Requires less radiation to produce an image compared to film radiography.
5) Doesn't require secondary image processing (compared to film or CR).
6) Images do not require film and chemicals– as required to process film.
7) Requires fewer retakes than film –underexposed or overexposed shots are minimized.
8) Produces images with the finest details.

b) Limitations
1) DDA panels have operating temperatures from −4 °F to 122 °F (−20 °C to 50 °C). At

temperatures above these limits, additional insulation is added to reduce instrument temperature exposure.

2) For storage, a broader range is acceptable, −40 °F to 158 °F (−40 °C to 70 °C).
3) The operating humidity should range from 10 % to 90 %. Extra precautions may be necessary to use DDA panels and their associated computers in the rain.

~~Film density radiography can be used in two separate methods: 1) detection of CUI-related damage; 2) using a logarithmic calculation to determine the wall thickness from a density variance.Profile radiography and film density radiography are complementary methods. The density/thickness reference curve should be developed using step wedges that are made from material that is radiographically similar to the piping being evaluated. The step wedge thickness should be twice the thickness of the pipe wall being evaluated.Film density radiography only measures the average wall thickness (AWT) of the piping and is commonly used on piping 12 in. (305 mm) or below; however, with some trade-offs, this technique can be used on larger diameter piping.The appropriate energy and film speed should be chosen when the film density measurement technique is utilized to achieve good image quality. It is important to locate the pit or local corrosion area correctly. The pitting should lie on film side during exposure to prevent an underestimation of its depth. The depth of the pitting and remaining wall thickness can be determined using the measured density of the pit and sound wall and a density/thickness reference curve [see Figure 12 c)]Profile radiography and film density radiography are complementary methods. Film density radiography can be used in two separate methods: 1) detection of CUI-related damage; 2) using a logarithmic calculation to determine the wall thickness from a density variance. The same principle can be applied to CR/DDA modalities; instead of measuring the density, we can now measure the grey value obtained from the computer software.Film density radiography only measures the average wall thickness (AWT) of the piping and is commonly used on piping 12 in. (305 mm) or below; however, with some trade-offs, this technique can be used on larger diameter piping.~~

~~The appropriate energy and film speed should be chosen when the film density measurement technique is utilized to achieve good image quality. It is important to locate the pit or local corrosion area correctly. The pitting should lie on film side during exposure to prevent an underestimation of its depth. The depth of the pitting and remaining wall thickness can be determined using the measured density of the pit and sound wall and a density/thickness reference curve [see Figure 12 c)]. The density/thickness reference curve should be developed using step wedges that are made from material that is radiographically similar to the piping being evaluated. The step wedge thickness should be twice the thickness of the pipe wall being evaluated. Advantages and disadvantages of film density radiography are as follows.~~

~~Advantages:~~

~~1) technique can locate irregular or scattered pits;~~

~~2) provides a permanent record of examined areas;~~

~~3) provides a relatively easy scanning method without the need for insulation removal.~~

~~a) Disadvantages:~~

~~1) corrosion products within pits can decrease film density and result in an incorrect determination of the wall thickness;~~

~~2) liquids present in the equipment (piping) will reduce the transmitted radiation;~~

    3) ~~an ultrasonic examination will also be required if density curves are not calculated;~~

    4) ~~piping or equipment would require insulation to protect the film at elevated temperatures.~~

~~The same principle can be applied to CR/DDA modalities; instead of measuring the density, we can now measure the grey value obtained from the computer software.~~

7.3.3.2.7 Software Enhanced Thickness Analysis for Digital Images

Software tools can improve the accuracy of thickness and wall loss estimates from profile and "film density" radiographic digital images. The tools can automate some analysis that was typically manually performed and allow the technician to focus on specific locations of concern. The tools can be integrated into software and present results immediately after the image is acquired in the field.

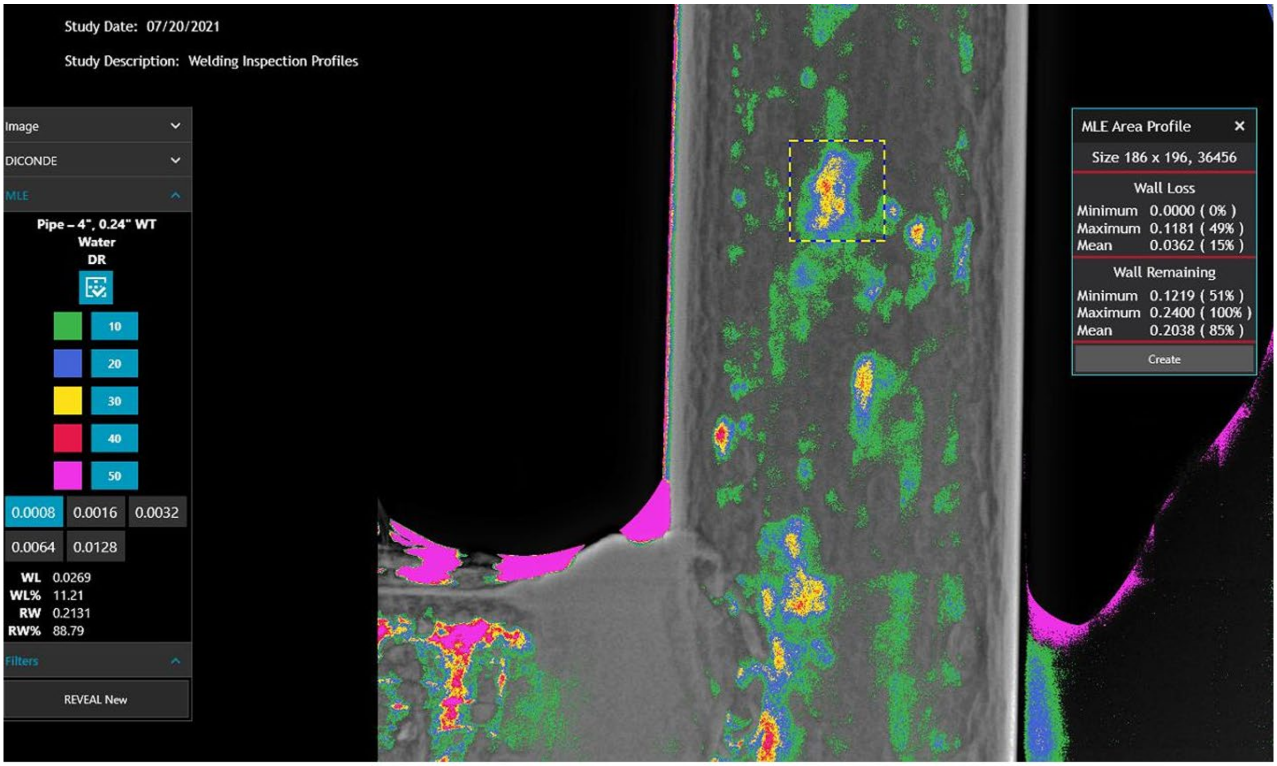
Being that the damage mode from CUI is typically localized corrosion, obtaining greater information from "film density" images is advantageous since the image has more coverage of the pipe area than a profile image of the wall in a single plane. Tools use the gray level information from the middle region of the pipe image to convert to wall loss information. It does not identify general corrosion or ECSCC given the lack of image contrast. Some tools can determine wall loss to an accuracy of +/-10% for pipe varying from NPS 3/4 to NPS 20. However, the area of interest where the wall loss is present should be centered to the detector to get the best accuracy. In addition, tools can perform some statistical analysis of select areas of an image. Figure 15 shows an example of pipe section analyzed using one of the tools.

Efficiency is improved tremendously as tools may not need the presence of step wedges and can provide quantitative results without needing to remove insulation in areas of concern for follow-up wall thickness measurements. Typical input parameters into tools can include source, pipe diameter, wall thickness, and whether pipe is filled or empty. There is no need for additional manpower using these tools provided existing technicians are trained to use these tools.

A good practice is incorporate radiographing validation samples with known wall loss at the beginning and end of a shift to validate the performance of the tool into procedures. An example of a validation sample image is shown in Figure 16.

Capabilities and limitations of these software tools for digital image analysis are identified below.

- a) Capabilities
    - 1) Detects and provides quantitative estimate of localized wall loss (to accuracy of +/- 10%).
    - 2) Can be used on NPS 3/4 to NPS 20
    - 3) Provides a permanent record of examined areas;
    - 4) Can account for the presence of liquid in pipe.
    - 5) Can minimize the number of radiographic images to obtains full diameter coverage
- b) Limitations
    - 1) Presence of corrosion products/scale can result in an underestimate of the wall thickness;
    - 2) Can not be used for general corrosion or ECSCC.



Study Date: 07/20/2021

Study Description: Welding Inspection Profiles

Pipe – 4", 0.24" WT
Water
DR

WL 0.0269
WL% 11.21
RW 0.2131
RW% 88.79

MLE Area Profile

Size 186 x 196, 36456

Wall Loss

Minimum	0.0000 (0%)
Maximum	0.1181 (49%)
Mean	0.0362 (15%)

Wall Remaining

Minimum	0.1219 (51%)
Maximum	0.2400 (100%)
Mean	0.2038 (85%)

Figure 15: Example image of a liquid-filled pipe using software tool to detect and quantify wall loss.

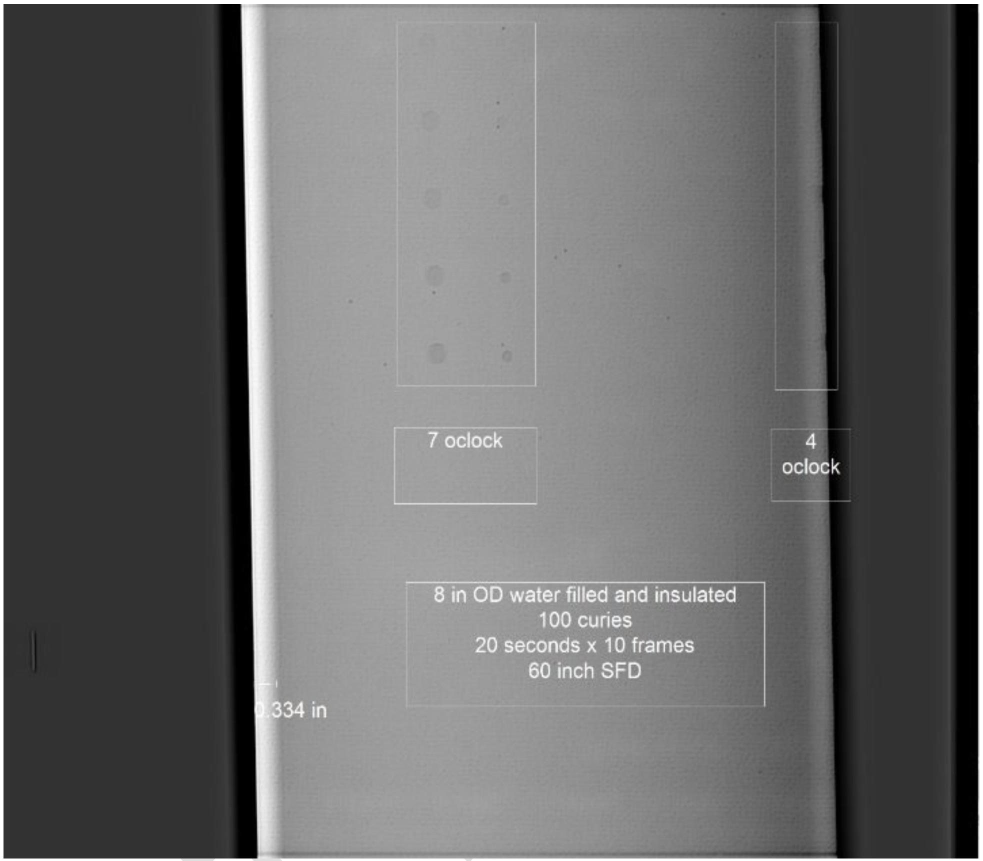


Figure 16: Example of an image of a validation pipe sample.

7.3.3.2.8 Real-time radiography (RTR)

RTR, commonly called fluoroscopy, is a manual, qualitative technique that provides a clear view of the pipe's OD through the insulation. Through the device's TV-type monitor, RTR shows the silhouette of the pipe OD as shown in Figure 17a. RTR does not use film – therefore, the images do not need development. RTR's device has a radiation source, and an image intensifier/detector connected to a C-arm as shown in Figure 17b. There are two categories of real-time radiography devices: an X-ray source and a gadolinium radioactive isotope (i.e., Ga-153) source.

Pipe CUI surveys often entail X-ray digital fluoroscopy. The equipment uses a low-level radiation source (≤75 KV/20W). The operator can adjust the voltage and/or amperage to obtain clearer images. It is safely operated without disrupting operating units or even confined spaces in areas where radiation alarms are not nearby. With its low-level radiation, RTR does not penetrate the pipe wall. Instead, the radiation penetrates the insulation and images the profile of the outer wall of the pipe. The operator may rotate the RTR equipment 360° around a pipe. Figure 17c shows RTR operators performing a pipe examination.

RTR is a screening technique that can detect the presence of external corrosion, moisture, ice and rust scabs from CUI/CUF. It does not detect ECSCC. An image with an irregular OD surface can be indicative of external corrosion. However, suspect locations will need follow-up examination with another technique (e.g. profile radiography, visual examination, etc.) to determine the extent or degree of corrosion present.

Most of the fluoroscopy systems come with a heads-up video display. A helmet-mounted, visor-type video display frees the system operator's hands to maneuver the C-arm while always keeping the image before the operator. The heads-up display also improves interpretation by shielding the screen from the sun.

Snapshots and videos can be stored containing suspect areas for CUI/CUF corrosion.

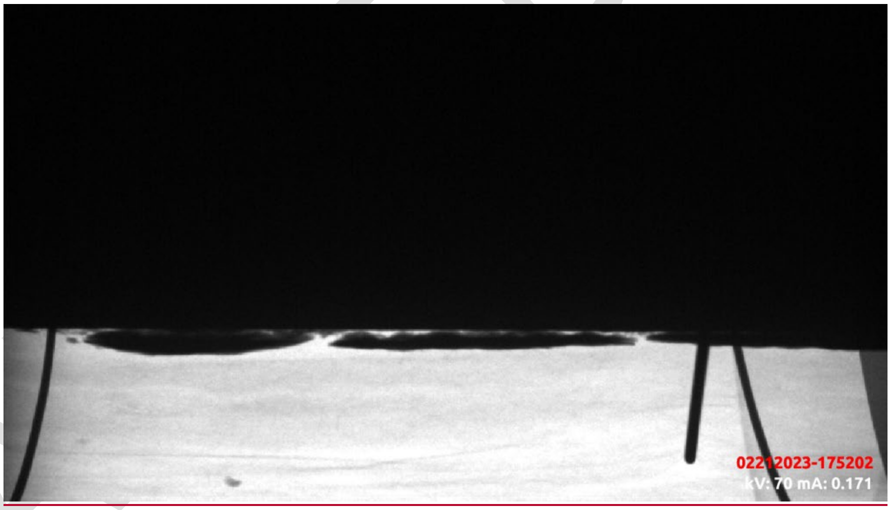
Capabilities and limitations for RTR are identified below.

a) Capabilities

1) Screens pipe surface profile for irregularities.
2) Fast set up and small exclusion areas allow large amounts of piping to be inspected quickly.
3) Can be performed while the equipment is in service.
4) Digital images are viewed in real time.
5) Still images can be printed on-site using a video printer or stored for evaluation later.
6) Video images (on some systems) can be stored for later review or algorithmic analysis.
7) X-ray-based devices generate radiation electrically, so they are safe when the power is off.

b) Limitations

1) RTR devices are listed as operating at -20° F to 120° F (-29° C to 49° C).
2) Congested piping areas need adequate clearance [i.e., up to 12 in. (30 cm)]
3) Wet insulation hampers testing.
4) Image quality deteriorates as the isotope decays for radioisotope devices.
5) Equipment utilizing radioactive material requires additional precautions to ensure that the source remains shielded when it is not being used. These precautions extend to the transportation and storage of radioactive material in accordance with jurisdictional regulations.
6) Equipment utilizing radioactive yield images with less resolution than the X-ray systems.



a) Display of scale on at the insulation to pipe surface

b) Photo of a RTR System

c) RTR Operators performing a CUI pipe examination

Figure 17: RTR Display and System

7.3.3.2.9 Flash Radiography (FR)

FR is a manual, qualitative technique for pipe which obtains profile images using a field portable X-ray tube, typically a pulsed generator method, rather than a radioactive source. Testing personnel arrange the beam tangentially to the pipe wall. The external wall corrosion is viewed as a variation in the pipe profile viewed from individual static images. The method uses X-ray equipment with fast radiation exposure time, and digital detection media. FR emits low radiation and may not require a roped-off exclusion area depending on local radiation safety requirements

FR is a fast inspection method to detect external corrosion from CUI and waterlogged insulation. The devices can produce through-wall images for insulated piping up to 2 in. (50 mm) in diameter and for pipes up to 12 in. (300 mm) in diameter to detect corrosion on the OD surface. It can be applied to items with diameters up to 36 in. (1 m) given sufficient source to detector distance and radiation output. The FR image contrast, image resolution, and penetrating ability are not as good as those for conventional radiography because of the limited radiation available and the large focal spot of the sources. Despite this, the image quality is sufficient to detect significant metal loss on the OD of the insulated pipe. The technique does not detect ECSCC.

Figure 18 shows an example of a flash radiography system for pipe profiling to detect wall thinning due to corrosion.

Capabilities and limitations for FR are identified below.

a) Capabilities

  1) Can detect external corrosion on pipe diameters up to 12 in (30 cm)

b) Limitations

  1) Temperature used from 0 °F – 120 °F (-18 °C – 49 °C). Outside of these ranges, require special considerations.
  2) Requires access to both sides of the pipe for the C-arm.

Figure ~~81~~18–Photo of a Flash Radiography System for Pipe Profiling to Detect Wall Thinning Due to Corrosion

7.3.3.2.10 Radiometric Profiling (RP)

RP is a manual semi-quantitative technique. RP measures the attenuation of a highly collimated radiation beam, with a very small radioisotope of Gadolinium-153 as an energy source, directed at a specialized detector. It then converts gamma rays to visible light in the form of photons. The detection system measures the transmitted photons and compares the results against a calibration scale.

RP is performed with a hand-held C-arm containing the energy source on one end and the energy detector on the other. The C-arm is connected to a portable computer with proprietary technology for recording captured data.

The pipe component is scanned with the C-arm (available in multiple sizes to accommodate different pipe diameters). When material is introduced between the energy source and an energy detector, the detector measures the amount of energy passing through the material (displayed as counts) and a pre-defined calibration allows for the conversion of detector measurements into calibrated values typically expressed in units compatible with the material being tested. The more material being measured the lower the counts and the higher the calibrated value. There is an inverse relationship between detector readings and the calibrated values.

RP can detect external corrosion from CUI as well as internal corrosion, wet insulation, and ice in insulation, and can measure insulation moisture density and pipe wall thickness. The minimum detection threshold, as for the diameter limitation, depends on the product inside the pipe, the pipe thickness, the insulation type, and the insulation jacketing type.

RP results in fast scans, averaging 150+/- test locations per day from a single technician. The RP equipment is highly portable. However, the technician requires extensive training and experience for proper interpretation and evaluation. RP can test in-process piping and does not require removal of insulation or radiation barricades.

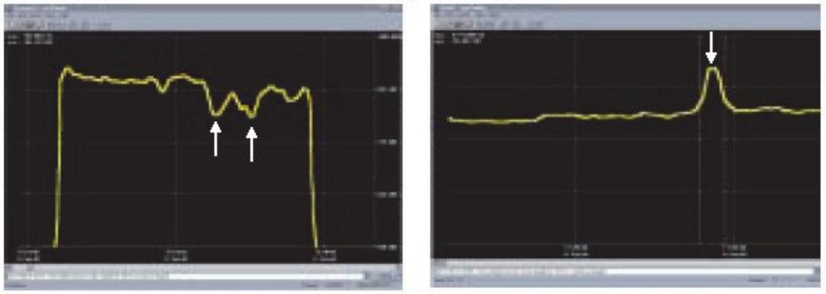
Results from RP are presented as graphs displaying double wall thickness as shown in Figure 19. Data is extracted and calculated to arrive at wall thickness accuracy values within 2-7%.

Capabilities and limitations for RP are identified below.

a) Capabilities
  1) Can detect internal and external pipe corrosion.
  2) Used for pipe 1/2 to 24 NPS.
  3) Detects indications as small as ¼" in diameter.
  4) No radiation exposure risk liability to company personnel and can be legally and safely performed during normal operation.
  5) Tests suspended and closely nested structures and piping.
  6) Can examine straight pipe, elbows, tees, reducers and metal structural components.
  7) Does not interfere with plant instrumentation (level gauges, etc.).
  8) Not affected by temperature of piping.
  9) Tests the entire circumference of the pipe or structure (instead of just a single spot or side).
  10) Real-time results.

b) Limitations
  1) Unable to examine near protruding features or at pipe supports
  2) Requires access to both sides of the pipe for the C-arm.
  3) Above a 1.2-inch (30 mm) combined wall thickness, smaller defects are difficult to detect.
  4) Cannot differentiate between ID or OD corrosion.
  5) Users require a radioactive materials license.

a) **Photo of a Radiometric Profiling System**



Pipe wall thinning **Location of weld**

b) **Display Showing Double-wall Thickness**

Figure 19~~:~~ - ~~15~~—Radiometric Profiling Display and System

~~There are various techniques involving radiographic methods that can be used to detect CUI damage. Radiography essentially requires a source of radiation opposite a detection medium that records the radiation either as a film or digital image. These include profile radiography, film density radiography, flash radiography, radiometric profiling, real-time radiography, computed radiography (CR), and digital detector array (DDA). A discussion of each method is presented below along with their advantages and disadvantages.~~

- ~~Film Profile Radiography—Film radiography is the dominant, volumetric nondestructive testing technique used throughout the world. The primary advantages of film radiography are that film is lightweight, flexible, and used in a variety of applications for many years with a proven track record. Despite this, film does have disadvantages. Namely, film processing requires a significant amount of time to develop radiographs (~20 min), specialized facilities for film processing (i.e. a dark room), and generates hazardous wastes that require disposal (namely, silver thiosulfate). Film radiographs have a limited shelf life, and require a temperature- and humidity-controlled storage environment.~~

- ~~Computed and DDA Profile Radiography—By contrast with film, DDA requires none of the above. Digital images can be generated, optimized, analyzed, stored, and distributed in electronic format.~~

  ~~CR [photostimulable luminescence (PSL) method]—Is a two-step radiographic imaging process; first, a storage phosphor imaging plate is exposed by penetrating radiation; second, the luminescence from the imaging plate's photostimulable luminescent phosphor is stimulated, detected, digitized, and displayed on an image display monitor.~~

~~The normal operating temperature is 23–86 °F (−5 °C to 30 °C). Short-term (hours) exposure to lower temperatures may be tolerated. At temperatures above 149 °F (65 °C), there is a risk of damaging the phosphor layer. Between 149 °F and 212 °F (65 °C and 100 °C), the polyester support layer may distort. Above 212 °F (100 °C), the phosphor layer may blister/buckle.~~

~~a) Advantages:~~

~~1) no silver-based film or chemicals are required to process film;~~

~~2) reduced film storage costs because images can be stored digitally;~~

~~3) requires fewer retakes due to underexposure or overexposure.~~

~~b) Disadvantages:~~

~~1) imaging plates can be damaged by rough handling.~~

~~DDA—A direct DDA system is an electronic device that converts ionizing or penetrating radiation into a discrete array of analog signals, which are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted upon the input region of the device. There are three technologies used in direct digital imaging systems:~~

~~1) amorphous silicon devices,~~

~~2) charge coupled devices, and~~

~~3) complementary metal oxide semiconductor devices.~~

~~The typical operating temperature is −4 °F to 122 °F (−20 °C to 50 °C). For storage, a broader range is acceptable, −40 °F to 158 °F (−40 °C to 70 °C). The operating humidity should range from 10 % to 90 %, and DDA should not be used in the rain.~~

~~Digital system images are available for viewing and analysis in seconds as compared to the minutes required in CR systems. The increased processing speed is a result of the unique construction of the pixels in a digital system, an arrangement that also allows an image resolution that is superior to CR and most film applications.~~

~~Advantages and disadvantages for DDA are shown below.~~

~~a) Advantages:~~

~~1) no secondary image processing required (compared to film or CR);~~

~~2) requires less radiation to produce an image compared to film radiography;~~

~~3) the image may be stored, emailed, or processed on a computer;~~

~~4) automated analysis assist software systems can be used to analyze the image, minimizing and mitigating the subjective assessment of an inspector.~~

~~b) Disadvantages:~~

~~1) DDA panel detectors require care to avoid damage;~~

~~2) rigid, heat sensitive;~~

    3) ~~lifetime of DDA panel detectors dependent on duty cycle/doses applied;~~

    4) ~~as a result of manufacturing, every DDA panel has some dead pixels.~~

~~Linear diode array (LDA)—A linear diode array is used for digitizing radiographic images. The LDA system consists of an array of photodiode modules. The diodes are laminated with a scintillation screen to create X-ray sensitive diodes. The scintillation screen converts the photon energy emitted by the X-ray tube into visible light on the diodes. The diodes produce a voltage when the light energy is received. This voltage is amplified, multiplexed, and converted to a digital signal.~~

~~The LDA is a real-time acquisition system, thus the component must move over the LDA or the LDA must move over the component; this can be ideal for CUI detection but due to the movement and vibration introduced, this method is not used for obtaining a wall thickness measurement through a tangent/profile method.~~

~~Flash Radiography—Flash radiography is an alternative to conventional gamma radiography. It is normally applied to pipes up to 12 in. OD to detect corrosion on pipe ODs under insulation. It can be applied to items with diameters up to 36 in. (1 m) given sufficient source to film distance and radiation output. This technique utilizes a field portable X-ray tube rather than a radioactive source.~~

~~The devices are capable of producing through-wall images for insulated piping up to 2 in. (50 mm) in diameter and for pipes up to 12 in. (300 mm) in diameter to detect corrosion on the OD of insulated piping. The technique uses X-ray equipment with a low radiation exposure time, fast X-ray films and intensifying screens, or digital detection media. The beam is arranged tangentially to the pipe wall and corrosion of the external wall shows up as a variation in the profile of the pipe. It saves costs normally attributed to the removal and reinstatement of insulation.~~

~~Flash radiography can also identify where insulation has become water-logged. Image contrast, image resolution, and the penetrating ability of flash radiography are not as good as that for conventional radiography because of the limited radiation available, the large grain film, and the relatively large focal spot of the sources. Despite this, the image quality is sufficient to detect significant metal loss on the OD of insulated pipe.~~

~~Figure 14 shows an example of a flash radiography system for pipe profiling to detect wall thinning due to corrosion. Advantages and disadvantages of flash radiography are as follows.~~

a) ~~Advantages:~~

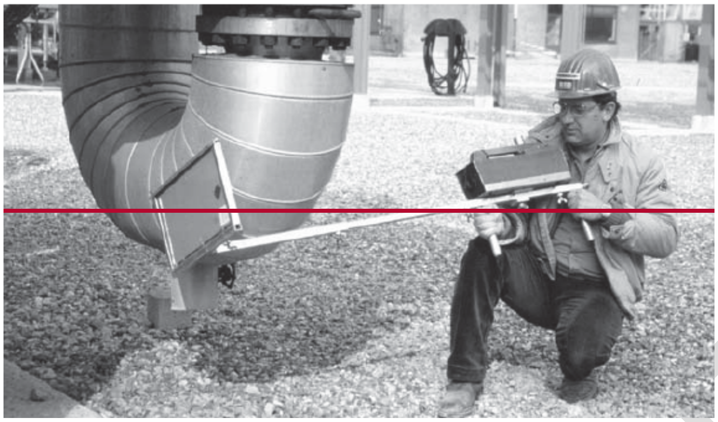
    1) ~~no need to rope off an exclusion area because of the low radiation available;~~

    2) ~~can identify water-logged insulation.~~

b) ~~Disadvantages:~~

    1) ~~inspection generally limited to pipe diameters up to 12 NPS;~~

    2) ~~image contrast and resolution not as good as conventional radiography because of the limited radiation available, the use of large grain film, and the relatively large focal spot of the devices.~~



~~Figure 14—Photo of a Flash Radiography System for Pipe Profiling to Detect Wall Thinning Due to Corrosion~~

- ~~Radiometric Profiling—These handheld radiographic systems use a gadolinium 153 radioactive source in combination with a solid-state scintillator that converts X-rays into photons (see Figure 15). The activity of the source and the length of the C-arm used determine the maximum density that the equipment can penetrate when looking for CUI. This equipment can allow estimation of the pipe wall thickness when shot through the center of the pipe. The limitations with regard to pipe and insulation diameter depends on the product inside the pipe, the density of the pipe material (thickness), the type of insulation, and the type of insulation jacketing being penetrated. In general, this equipment is capable of inspecting insulated standard wall thickness pipe with an overall OD of up to 24 in.~~

  ~~Advantages and disadvantages of radiometric profiling are as follows.~~

  ~~a) Advantages:~~

    ~~1) suitable for piping from $^{1}/_{2}$ to 24 NPS;~~

    ~~2) no radiation barricade is required to utilize device;~~

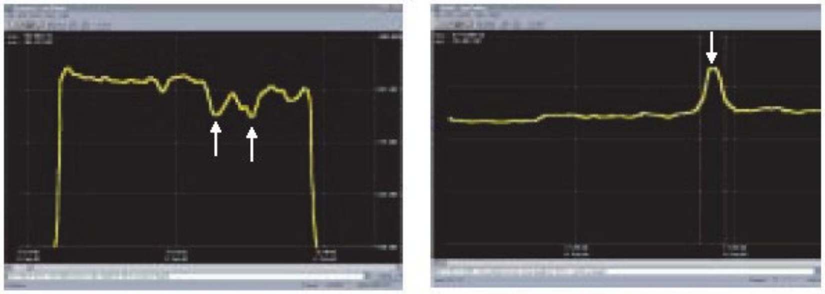
    ~~3) very portable and may be operated by a single technician.~~

  ~~b) Disadvantages:~~

    ~~1) measures the remaining combined double-wall thickness, not the pipe wall thickness of the corroded area;~~

    ~~2) cannot differentiate between inside diameter (ID) and OD corrosion;~~

    ~~3) requires a radioactive materials license.~~



Pipe wall thinning

Location of weld

~~**a) Display Showing Double-wall Thickness**~~

~~**b) Photo of a Radiometric Profiling System**~~

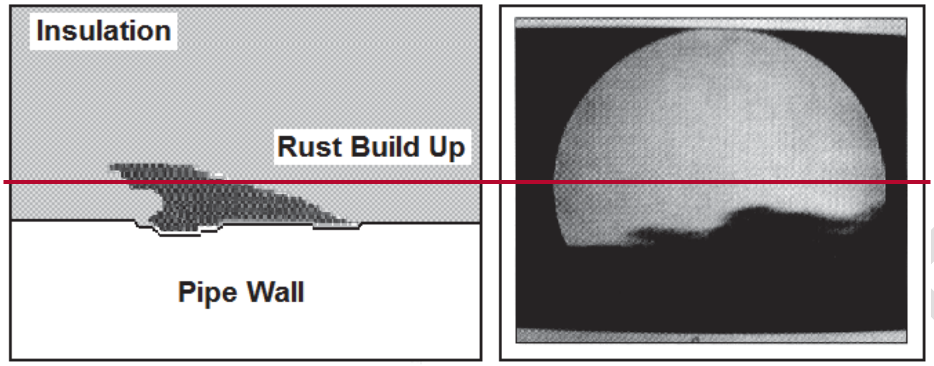
~~**Figure 15—Radiometric Profiling Display and System**~~

- ~~Real-time Radiographic Examination Method (RTR)—RTR, commonly referred to as fluoroscopy, provides a clear view of the pipe's OD through the insulation, producing a silhouette of the OD of the pipe on a TV-type monitor that is viewed during the inspection [see Figure 16 a)]. No film is used or developed. The real-time device has a radiation source and image intensifier/detector that are connected to a C-arm [see Figure 16 b)]. There are two categories of real-time radiography devices, one using an X-ray source and one using a gadolinium radioactive isotope (i.e. Ga-153) source. Each has its own advantages and disadvantages; however, the X-ray systems deliver far better resolution than the isotope systems.~~

  ~~The X-ray digital fluoroscopy equipment operates using a low-level radiation source (≤75 KV). The equipment allows the voltage and/or amperage to be adjusted to obtain the clearest image and allows for safe operation without disruption in operating units or even confined spaces. As a result of the low-level radiation, the radiation does not penetrate the pipe wall. Instead, the radiation penetrates the insulation, and images the profile of the outer wall of the pipe. In order for CUI to be detected on insulated pipe, it may be necessary to rotate the fluoroscopy device 360° around a pipe. In many instances, the image may indicate a rough surface of the OD of the pipe indicative of corrosion; however, other means should be employed to determine the extent or degree of corrosion present.~~

  ~~Since the radiation is generated electrically, the instrument is perfectly safe when the power is off. Equipment utilizing radioactive material requires additional precautions to ensure that the source is shielded when not being used. These precautions extend to transportation and storage of radioactive material in accordance with NRC or state-mandated regulations.~~

  ~~Most of the fluoroscopy systems come with a heads-up video display. A helmet-mounted, visor-type video display frees the system operator's hands to maneuver the C-arm while keeping the image before the operator at all times. The heads-up display also improves interpretation by shielding the screen from the sun. The video images can be printed on site using a video printer or recorded for evaluation at a later date.~~



~~**a) Representation of CUI (left) and a Silhouette Display of CUI (right)**~~

~~**b) Photo of a Real-time Radiography System**~~

~~**Figure 16—RTR Display and System**~~

~~Advantages and disadvantages for real-time radiography are shown below.~~

~~a) Advantages:~~

  ~~1) images are easily viewed because they are digital and can be electronically stored and retrieved using a computer;~~

  ~~2) there is no maximum size limitation since multiple arrays can be assembled to view large areas.~~

~~b) Disadvantages:~~

  ~~1) adequate clearance [i.e. up to 12 in. (30 cm)] required on piping in congested areas;~~

  ~~2) wet insulation hampers testing;~~

  ~~3) radioisotope system image quality deteriorates as isotope decays.~~

7.3.3 ~~7.3.3.2.4~~ Pulsed Eddy Current (PEC) Method

The PEC method is a semiquantitative technique using electrical current through a probe coil to create a magnetic field in the test material. Eddy currents are generated in the test material when the current in the probe coil is switched off. The eddy currents diffuse inward and decrease in strength over time which is monitored by the probe coil. The thickness of the component is related to the length of time it takes for the eddy currents to show a change of decay rate when eddy currents reach the back wall of the metal. The greater the wall thickness of the component, the longer it takes for the eddy currents to reach the back wall. Figure 20 shows the principles of the PEC method.

PEC is a noncontact, electromagnetic examination method used to detect the average wall loss of carbon and low alloy steel materials. It can be used on insulated equipment through aluminum, stainless steel, galvanized steel and CSPE jacketing and on fireproofed equipment. PEC can be delivered manually or semi-automated (with encoded distance).

The area where the measurement is taken is referred to as the “footprint.” The probe is designed in such a way that the magnetic field focuses on an area on the surface of the component. The thickness measured by the technique is the average wall thickness over the averaging area. The size of the area is dependent on the insulation, component thickness, and probe design. In general, the footprint size is approximately the same as the insulation thickness. Figure 21 illustrates the difference between average and minimum wall thickness within the footprint.

~~ToD (threshold of d~~Detection~~)~~ threshold is defined by the inspection footprint which is a function of combined wall and insulation thickness. Because the thickness measured is the wall thickness over an averaged area, defects smaller than the probe footprint are undersized.

PEC instruments are available with~~ as~~ single element and/or multiple element arrays.~~can be perfomed~~ PEC array systems can provide higher productivity and detection performance compared to single element systems. Figures 22 and 23 show single element and array PEC instruments components.

The PEC method using the medium array can cover approximately 1.5 ft/min (0.5 m/min) for full circumferential coverage of an 8” pipe with 2” insulation. Scan speed decreases with increasing wall thickness. Typically, individual probe and array configurations require only a single technician. Depending on work environment (elevated piping, scaffolding location, etc.) and size of the equipment (large vessels, long pipe runs or sphere leg inspections), additional personnel may be required for efficiency.

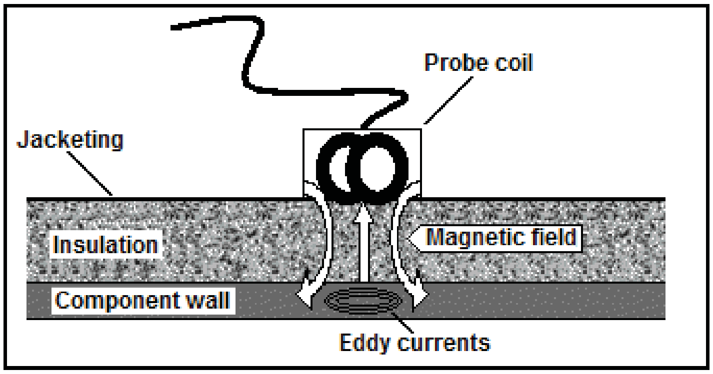
PEC will undersize flaws smaller than the averaging area of the probe. To improve their measurement accuracy, specific algorithms can be processed on an isolated portion of the C-scan to calculate a compensated wall thickness measurement and reduce the undersizing effect. Since the technique measures the average rather than the minimum component thickness, the technique is not suitable to detect pitting that can be highly localized.

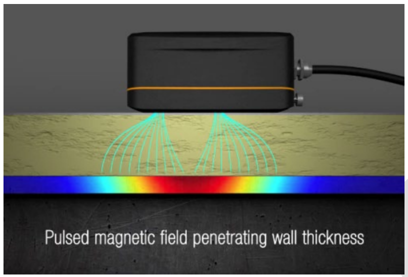
PEC displays show the decay of the eddy currents, C-scan wall thickness and compensated wall thickness, and a log-log signal response vs. time graph. Several typical PEC displays are shown in Figure 24.

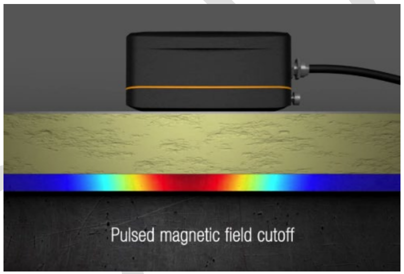
Capabilities and limitations for the PEC method are identified below.

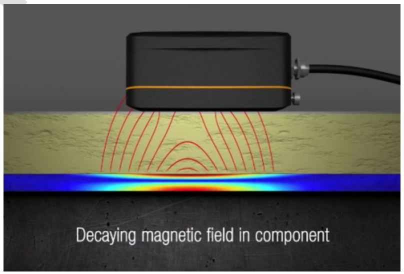
a) Capabilities
   1) Can detect local and general wall loss occurring from both OD and ID but cannot discriminate between them.
   2) Up to 12 in. (305 mm) of insulation and jacketing.
   3) Minimum diameter 1 in. (25 mm), up to flat surfaces
a) Limitations

1) Edge effect near metallic structures; the compensated wall thickness algorithm can be used to compensate for the electromagnetic contribution of masses such as a flange, resulting in better wall loss sizing.
2) PEC response can be influenced by internal attachments, such as vessel tray support rings.
3) Cannot detect small pitting or through-wall defects.
4) Magnetic permeability variations in vessel plate or pipe material may increase PEC "noise level" and reduce detection sensitivity.
5) Suitable for carbon and low alloy steel equipment.









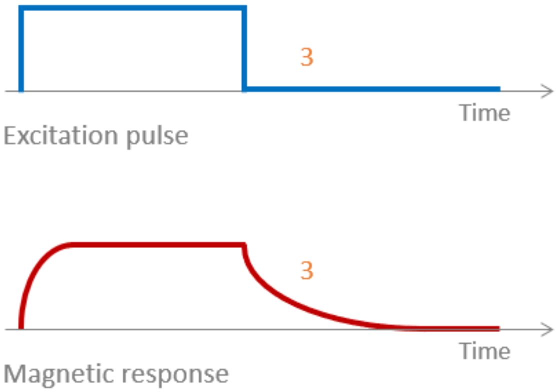


Figure 20—Principle of Operation the Pulsed Eddy Current Technique

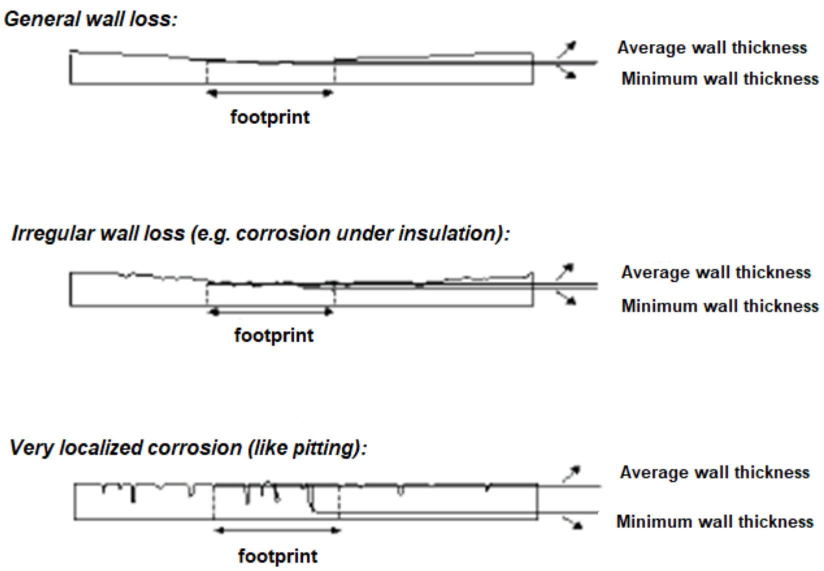


Figure ~~921~~21—Difference Between Average and Minimum Wall Thickness Within the Footprint

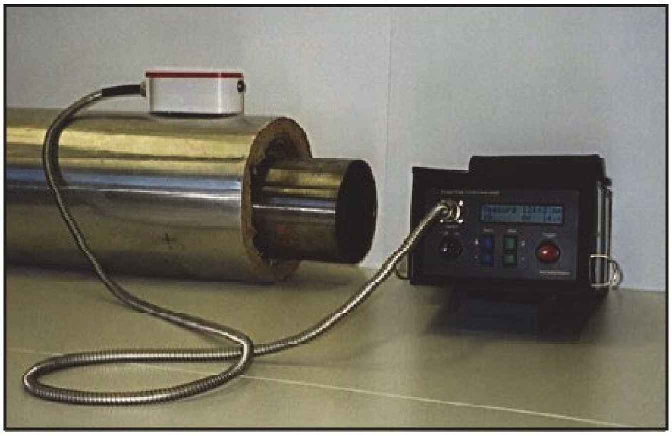
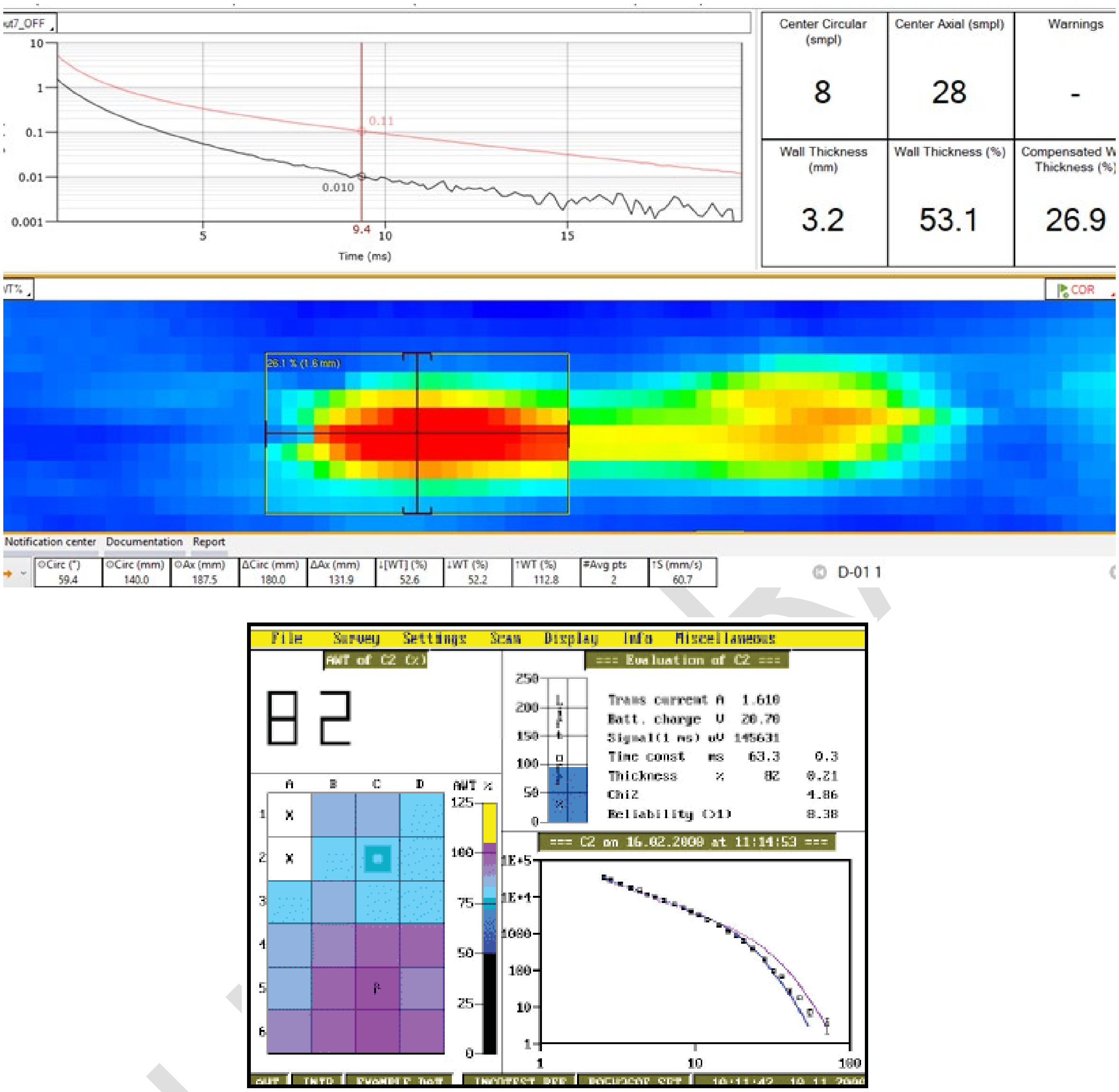


Figure 22—A Pulsed Eddy Current Instrument with Probe and being used during an examination.

Figure 23—A Pulsed Eddy Current Array System



Center Circular (smpl)	Center Axial (smpl)	Warnings
8	28	-
Wall Thickness (mm)	**Wall Thickness (%)**	**Compensated W Thickness (%)**
3.2	53.1	26.9

⊙Circ (°)	⊙Circ (mm)	⊙Ax (mm)	ΔCirc (mm)	ΔAx (mm)	↓[WT] (%)	↓WT (%)	↑WT (%)	#Avg pts	↑S (mm/s)
59.4	140.0	187.5	180.0	131.9	52.6	52.2	112.8	2	60.7

=== Evaluation of C2 ===

```
Trans current  A    1.610
Batt. charge   U    20.70
Signal(1 ms) uU    145631
Time const    ms    63.3      0.3
Thickness      %      82      0.21
Chi2                          4.86
Reliability (>1)              8.38
```

=== C2 on 16.02.2000 at 11:14:53 ===

Figure 24—A PEC Display Showing the Decay of the Eddy Currents (top), Wall Thickness and Compensated Wall Thickness (middle), and a Log-Log Representation of the Inspection (bottom)

~~PEC has been used in recent years to detect areas of wall thinning on insulated piping through aluminum, stainless steel, or galvanized steel jacketing. It is also used to inspect fireproofed legs on storage spheres. It is a noncontact, electromagnetic examination method used to detect the average wall loss of carbon and low alloy steel materials. A photo of a pulsed eddy current system is shown in Figure 17. A photo of a single element pulsed eddy current system is shown in Figure 17. Pulsed eddy current array systems (see Figure 18) are also available, and, they can provide higher productivity and detection performance compared to single element systems.~~

~~A magnetic field, created by an electrical current in the probe coil, penetrates the jacketing and magnetizes the pipe wall. Current, in the probe coil, is then switched off to cause a sudden drop in the magnetic field. As a result of the change in the magnetic field, eddy currents are generated in the pipe wall. These eddy currents diffuse inward and decrease in strength. This decrease in the strength of the generated eddy currents is monitored by the probe coil. The thickness of the component is related to the length of time it takes for the eddy currents to show a change of the decay rate when eddy currents reach the back wall of the metal. The greater the wall thickness of the component, the longer it takes for the eddy currents to reach the back wall. Figure 19 and Figure 20 show a representation of the pulsed eddy current technique and a pulsed eddy current display.~~

~~The area where the measurement is taken is referred to as the "footprint." The probe is designed in such a way that the magnetic field focuses on an area on the surface of the component. The thickness measured by the technique is the AWT over the averaging area. The size of the area is dependent on the insulation, component thickness, and probe design. In general, the footprint can be considered to be on the order of the insulation thickness. Because the thickness measured by the technique is the wall thickness over an averaged area, defects smaller than the probe footprint are undersized. Specific algorithms can be processed on an isolated portion of the C-scan to calculate a compensated wall thickness measurement and reduces the undersizing effect. Since the technique measures the average rather than the minimum component thickness, the technique is not suitable to detect pitting that can be highly localized. This effect is shown in Figure 21.~~

~~PEC can be used on carbon and low alloy steel equipment and piping through up to 12 in. (305 mm) of insulation and jacketing. The advantages and disadvantages for pulsed eddy current inspection are shown below.~~

~~a) Advantages:~~

  ~~1) noninvasive, noncontact method that does not require surface preparation;~~

  ~~2) inspects through various types of coatings/insulations including CSPE jacketing;~~

  ~~3) detects OD and ID corrosion;~~

  ~~4) in-service inspections;~~

  ~~5) can be used between –150 °F and 930 °F (–100 °C and 550 °C);~~

  ~~6) inspect small pipes with diameter down to 1 in. (25 mm), up to flat surfaces.~~

~~b) Disadvantages:~~

  ~~1) screening tool; provides relative measurement to a reference thickness;~~

  ~~2) unable to discriminate near-side and far-side defects;~~

  ~~3) impossible to detect small pitting;~~

  ~~4) undersize flaws smaller than the averaging area of the probe; the compensated wall thickness algorithm can be used for better measurement accuracy;~~

  ~~5) edge effect near metallic structures; the compensated wall thickness algorithm can be used to compensate for the electromagnetic contribution of masses such as flange, resulting in better flaw sizing;~~

  ~~6) magnetic permeability variations in vessel plate or pipe material may increase PEC "noise level"~~

~~and thereby potentially reduce reliable detection sensitivity;~~

  7) ~~vessel internals (e.g. tray support rings) may influence PEC response;~~
  8) ~~impossible to detect through-wall defects.~~

~~Qualitative Methods~~

~~7.3.3.3.1 General~~

~~These are inspection methods that attempt to assess the quality of the insulation/fireproofing system as an indirect measure of the potential for surface corrosion damage. These methods are conducted without removing the insulation or fireproofing from the equipment or structural support and include the visual inspection with partial removal of the insulation, the neutron backscatter, and thermal/infrared inspection methods.~~

~~7.3.3.3.2 Visual Examination Method with Partial Removal of Insulation~~

~~The most reliable technique to detect CUI is to physically remove the insulation and visually inspect the surface of the vessel or piping. This approach is costly since equipment must be deinsulated and reinsulated and frequently requires scaffolding to access areas for inspection. Removing smaller sections of insulation (i.e. windows) is useful for advanced inspections to help prioritize equipment for remediation or more thorough follow-up inspections. Using insulations materials that can easily be removed and reused allow for more frequent and lower cost inspection activities.~~

~~The placement and size of these inspection windows (i.e. holes cut in the insulation to expose the equipment external surface for inspection) is very important. Windows should be cut where CUI is most likely such as at poorly sealed insulation penetrations, at low points in the piping system where water can collect, at insulation support rings or vessel stiffening rings, or at areas where the insulation jacketing is in poor condition and water can penetrate the insulation system. The areas where insulation is removed should be large enough to be representative of the condition of the equipment. It may be necessary to cut several windows in suspect locations because of the difficulty in predicting where CUI damage has occurred.~~

~~For example, on a large drum or tower, it may be necessary to remove a vertical strip of insulation to represent different temperature zones in the equipment and to locate stiffener or insulation support rings. Once located, specific insulation support rings or stiffeners may then be selected for insulation removal around the circumference of the vessel to locate areas where degradation may be the most severe.~~

~~A variant of partial insulation removal is to perform visual examination at inspection ports in the insulation. This approach is of minimal value because of the limited amount of surface area exposed for inspection.~~

~~Advantages and disadvantages of visual inspection with partial insulation removal or at inspection ports are as follows.~~

a) ~~Advantages:~~
  1) ~~costs associated with insulation removal/reinstallation are significantly reduced compared to complete removal of insulation;~~
  2) ~~limited exposure to hot surfaces for personnel.~~

b) ~~Disadvantages:~~

~~c) CUI damage can be missed since only a limited area of the equipment is inspected;~~

~~d) special precautions are necessary on asbestos insulated systems;~~

~~e) windows cut in insulation pose a potential leak path for water ingress if insulation is not effectively repaired/sealed.~~

7.3.3.~~3.3~~4 Neutron Backscatter Examination Method

The neutron backscatter technique ~~utilizes~~uses an americium 241 radioactive source to emit fast neutrons with high energies through the insulation jacketing. When these fast neutrons interact with hydrogen atoms, they release energy and are transformed into slow or thermal neutrons. The thermal neutrons are scattered in all directions but have a short travel path. Some of these thermal neutrons are scattered back toward the scanning head and counted by a sensitive detector. The more hydrogen atoms present in a material, the more thermal neutrons are produced and counted by the detector. Figure 25 shows a neutron backscatter system.

Since the technique identifies the presence of hydrogen atoms, it detects water in the insulation and fireproofing system. This can provide data to focus CUI inspection tasks. Note, however, that the technique will also detect hydrocarbons in the insulation. It does not detect or measure metal loss from corrosion.

The technique can inspect at rates up to 10 feet per minute. A typical neutron backscatter crew, normally one to two persons, can inspect over 1,000 feet of insulated piping per day.

Special consideration should be given to the neutron backscatter operator and proper training and qualification should be provided in line with the manufacturer's recommendations and guidelines. In addition, they are required to be trained in radiation safety and proper usage.

Data logging capabilities allow the storage of thousands of measurements with the location, date, time, and direction noted. The measurements can be stored and compared against historic data to determine changes in moisture content over time.

Capabilities and limitations for the neutron backscatter examination method are identified below.

a) Capabilities
   1) Detects areas of trapped moisture to correlate with identifying areas for potential CUI and CUF.
   2) Can be used on insulated piping, vessels, and aboveground storage tanks.
   3) Displays moisture data directly in units of interest on an electronic display and the data logging capabilities allow the storage of measurements and transfer to download or printout.

b) Limitations
   1) Devices cannot distinguish between water, hydrocarbons, acids, bases, and organic liquids. However, the presence of any of these fluids would warrant follow-up inspection.
   2) Only effective while the insulation is wet; the technique is not effective if sufficient time has elapsed for the insulation to dry out.
   3) Operators are required to be trained in radiation safety and proper usage per jurisdictional requirements.
   4) Access is limited only by the physical size and configuration of the detector assembly as it relates to the piping, vessel, or aboveground storage tank to be inspected.

~~The neutron backscatter technique works because of the interaction of neutrons with hydrogen atoms. The technique utilizes an americium 241 radioactive source to emit fast neutrons with high energies through the insulation jacketing. When these fast neutrons interact with hydrogen atoms, they release energy and are transformed into slow or thermal neutrons. The thermal neutrons are scattered in all directions, but have a short travel path. Some of these thermal neutrons are scattered back toward the scanning head and counted by a sensitive detector. The more hydrogen atoms present in a material, the more thermal neutrons produced and counted by the detector. Figure 22 shows a photo of a neutron backscatter system.~~

~~It should be noted that this technique detects hydrogen atoms. Therefore, these devices cannot distinguish between water, hydrocarbons, acids, bases, and organic liquids. However, the presence of any of these fluids would warrant follow-up inspection.~~

~~Advantages and disadvantages for the neutron backscatter inspection method are as follows.~~

~~a) Advantages:~~

  ~~1) detects the presence of water or hydrocarbon under insulation jacketing;~~

  ~~2) easy-to-use method that can be used to rapidly scan insulated surfaces.~~

~~b) Disadvantages:~~

  ~~1) detects the presence of water or hydrocarbon in the insulation system, not corrosion;~~

~~2) technique is only effective while insulation is wet; technique is not effective if sufficient time has elapsed for insulation to dry out.~~

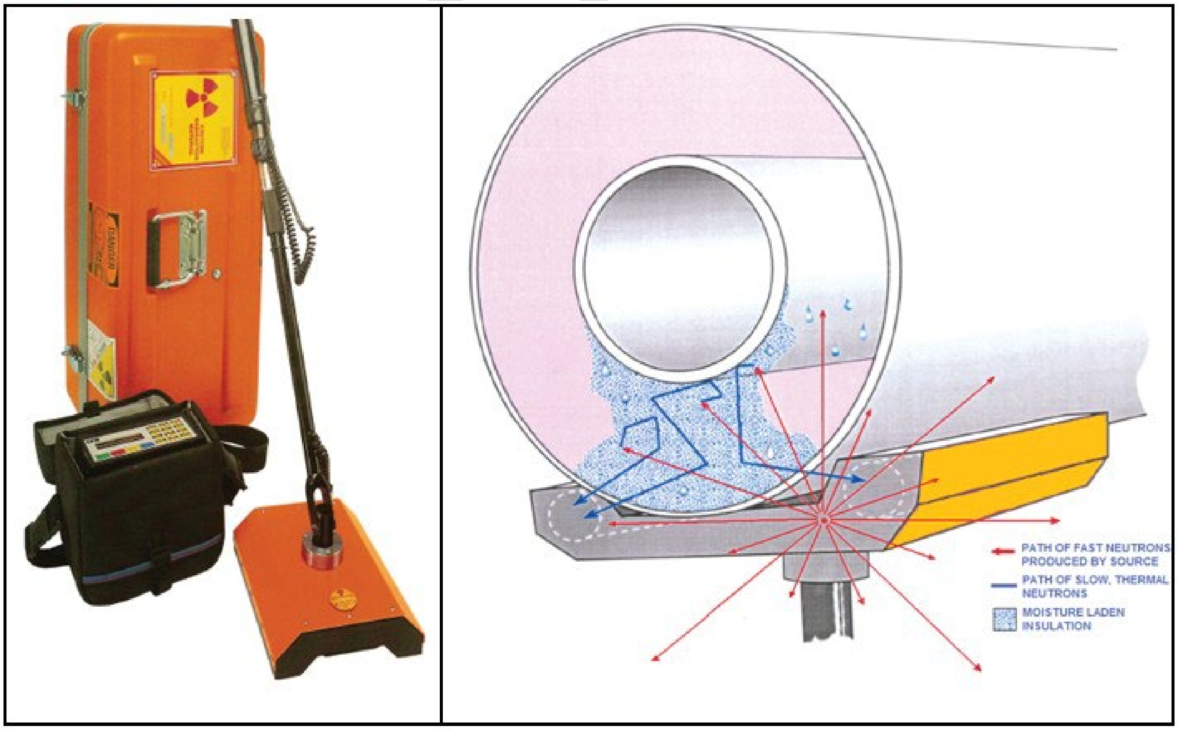


Figure ~~22~~25—A Photo of a Neutron Backscatter System

7.3.3.~~3.4~~5 Thermal/Infrared Imaging Examination Method

Thermal/Infrared Examination Method (IR) is a rapid, passive inspection technique that quantifies thermal/heat gradients through visualization produced using specialized infrared (IR) cameras. IR cameras can typically detect surface temperature variations on equipment within 9ºF or (5ºC) and perform well where differentials across any given area are 18°F (10°C) or greater.

Accurate temperature measurements with IR cameras are dependent on variables such as, but not limited to, equipment type, component emissivity values, technician experience and surrounding ambient temperature and humidity conditions. Temperature variations are displayed in color or gray scale variations identifying what are commonly referred to as “hot spots” or “cold spots”.

IR inspection is usually performed with stationery or handheld cameras and sweeping across a given target area of equipment. IR inspection often can observe targeted inspection areas 65 feet (20 m) away with unobstructed accessibility or line of sight. However, obstructions from surrounding piping, equipment or structures may require much closer access. Figure 26 provides examples of IR thermographic images.

IR is used to detect wet spots in the insulation due to a temperature difference between the dry and the wet insulation. This is a qualitative screening tool to identify areas which may have conditions conducive for CUI.

To improve the results, it is common to conduct IR inspection in the early evening since wet or compromised insulation can hold heat absorbed from the daylight sun/ solar rays much longer than dry insulation. This allows for greater thermal gradients to be more apparent. In addition, surface areas should be dry and so after rain, the examination should be performed after the surfaces are completely dry. In some cases, the presence of algae or other organic growth may need to be removed for improved detection. Lastly, assessing the emissivity values for the surface areas of the components or items under examination will improve the accuracy of temperature measurements.

Data from an IR camera are color or gray scale images where the color and/or shade represents different surface temperatures. Analyzing these images for “hot” and “cold” spots, depending upon the equipment temperature, become suspect locations. Owner-operators often develop a screening ranking system to assist with prioritization for follow-up inspections, i.e. minor, moderate or severe.

Coupling the inspection with neutron backscatter techniques, which are designed specifically for moisture detection, can enhance confidence in the screening. However, to detect actual CUI damage in suspect areas, additional examination is necessary (e.g. RT, visual examination with insulation removal, etc).

Summaries and assessments should be accompanied by data, images, screenshots, etc. as required to support findings. Comparative data (data collected over multiple times) should be organized to provide appropriate delta measurements.

Capabilities and limitations for IR are identified below.

a) Capabilities
  1) Detects damaged or wet insulation on insulated piping and vessels.
  2) Method is nonintrusive and noncontact.
  3) Can examine challenging geometry and locations such as pipe/vessel supports, insulation rings and protruding features (i.e. nozzles, branch connections)
  4) Use as a screening tool for initial detection of moisture sites subject to follow up inspections for CUI.
  5) Works well with CSPE jacketing which has an average emissivity of 0.96.

   6) Can be used to show moisture egress over time by comparing periodic examination results.

b) Limitations
   1) Not able to detect or quantify corrosion but environmental changes where corrosion may occur such as, compromised, or wet insulation, variations in steam or electrical tracing, etc.
   2) Becomes difficult to utilize on shiny, uncoated metal jacketing or where emissivity values are low.
   3) May be difficult to inspect during daylight hours, specifically during mid-day where the sun is most directly overhead.
   4) Limited to effects on external “immediate surface area” only.

~~The thermal/infrared imaging examination method (i.e. thermography) is another approach for assessing the potential for CUI on insulated vessels and piping. Thermography is a rapid, passive inspection technique that produces a heat picture of the surface of a component using a thermal imaging infrared (IR) camera. IR cameras are used to detect damp spots in the insulation due to a temperature difference between the dry and the wet insulation.~~

~~IR cameras can typically detect surface temperature variations on equipment down to a few degrees; however, there must be a temperature differential across the thickness of the component of around 18 °F (10 °C) for an ideal scenario. This is very general as there are several factors that affect this minimum resolvable temperature difference, including equipment type, component surface emissivity, technician experience, etc. Temperature variations on the component are displayed as different colors. Depending on the temperature of the product contained, “hot” or “cold” spots on the thermograph show up because of the effect of moisture increasing local thermal conductivity in the component. Thermography is often carried out from as far away as 65 ft (20 m). Full inspection coverage can at times be difficult because of site obstructions such as existing piping or equipment during IR photo shooting. Figure 23 shows examples of IR thermographs.~~

~~In some instances, IR surveys are conducted in conjunction with neutron backscatter examination. Conducting the IR survey two to three hours after the sun has set is advantageous since wet insulation holds the heat absorbed from solar rays longer than dry insulation. This can tend to promote more contrast in the thermograph. In general, thermographic inspection for CUI should be done in the absence of strong gusty winds (i.e. nonwindy conditions) since wet insulation maintains its heat longer. It should be noted that while water may be detected with this technique, it does not necessarily mean that CUI is occurring.~~

~~Advantages and disadvantages for thermal/infrared inspection are as follows.~~

~~a) Advantages:~~

   ~~1) rapid method to detect damaged or wet insulation;~~

   ~~2) noninvasive, noncontact method that does not require direct access to the insulated surface (i.e. can be done from ground level without scaffolding);~~

   ~~3) easy-to-use method to highlight areas requiring inspection follow-up;~~

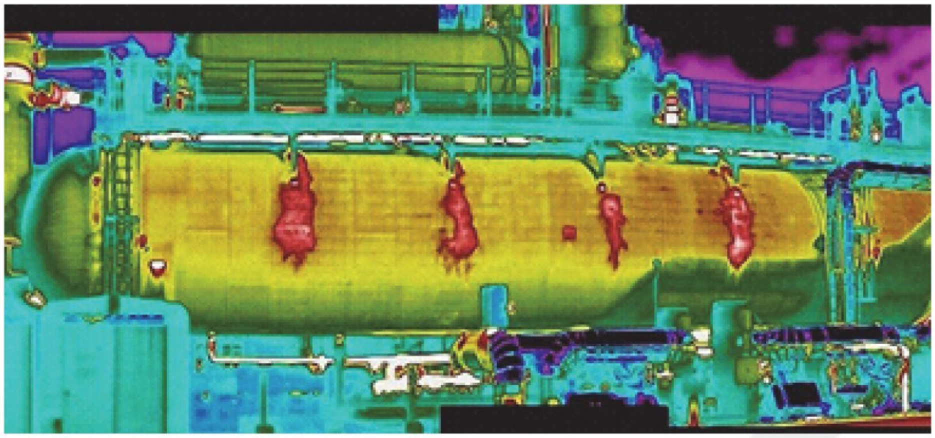
   ~~4) works particularly well with CSPE jacketing, which has an emissivity of 0.96.~~

~~b) Disadvantages:~~

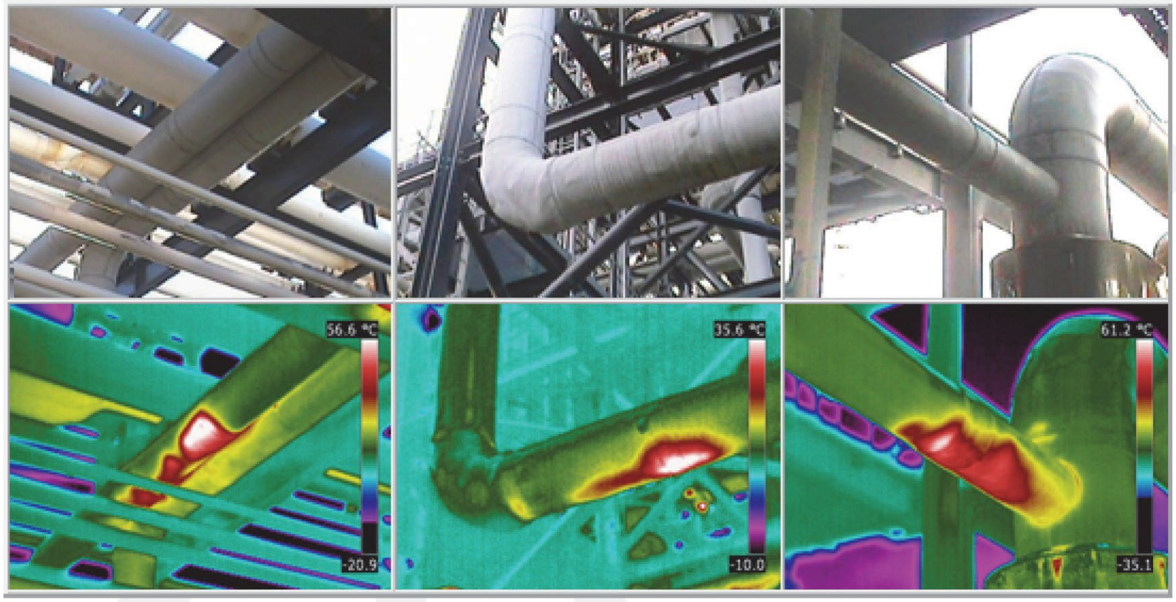
   ~~1) does not detect corrosion but only areas where insulation may have been compromised (i.e. damaged or wet insulation);~~

~~2) not effective method if insulation has had sufficient time to dry out;~~

~~3) technique is easily defeated by thermal reflections on low-emissivity jacketing and the reflective shiny surface of uncoated metal jacketing.~~



a) Desalter Vessel with CSPE Jacketing Showing Water Intrusion Under the Insulation



b) Saturated Insulation on Piping Finished with CSPE Jacketing

Figure 26~~23~~—Thermographs Showing Areas with Wet Insulation (in red)

7.3.3.~~3.5~~6 Moisture Detection Imaging (MDI)

MDI is a qualitative, Compton backscatter technique. As X-rays hit an object, some are absorbed, producing a transmission X-rays image, and others are “scattered” (Compton scattering). Backscatter images are formed from the X-rays that are scattered back toward the X-rays source and the collection detector. Compton scattering is material-dependent, with the lower atomic number materials scattering more strongly than the higher numbered ones. Therefore, this device can detect water as well as~~cannot distinguish between water,~~ hydrocarbons, acids, bases, and organic liquids.

MDI is deployed by manual means and can be performed from rope access. This system is battery powered and highly portable. MDI uses a low energy X-ray source which does not require a jurisdictionally certified radiographer to operate. Figure 27 illustrates details of the instrument.

This system focuses on the detection of moisture conditions under insulation which can lead to CUI conditions.

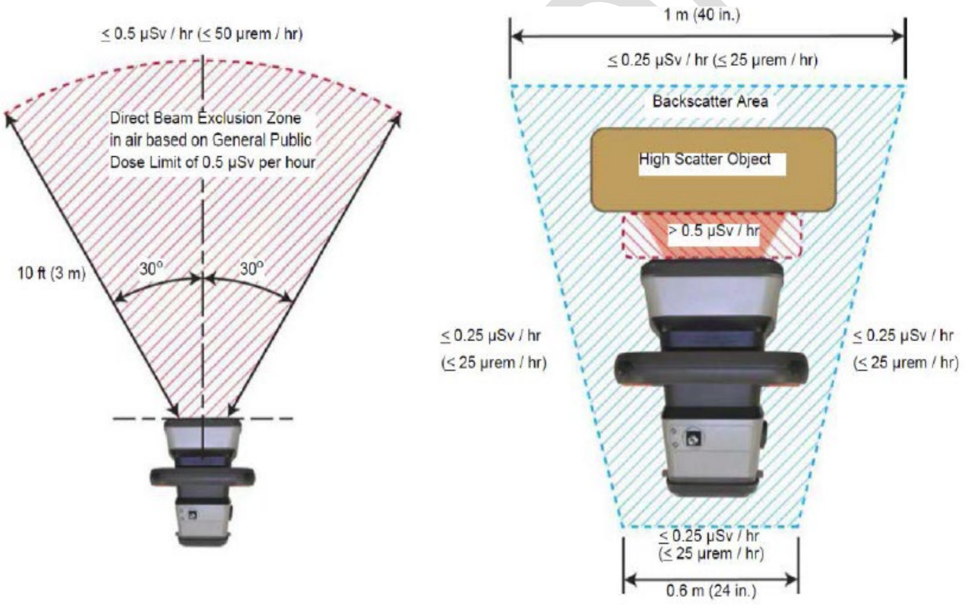


Figure 27: Illustration of MDI instrument characteristics

Technicians should have received proper training and have a good understanding of the technique. Complex piping and geometries can see a production rate of 900 ft. (275 m) per-shift, with 1800 ft. (550 m) per-shift on straight run piping based on a 12-hour shift.

The results are considered qualitative as they show locations where the conditions for CUI may be present but do not represent actual CUI damage. Suspect areas of water presence require additional examination (e.g. visual examination after stripping insulation) to verify if CUI damage is present or if they are just early pre-CUI damage locations suitable for mitigation.

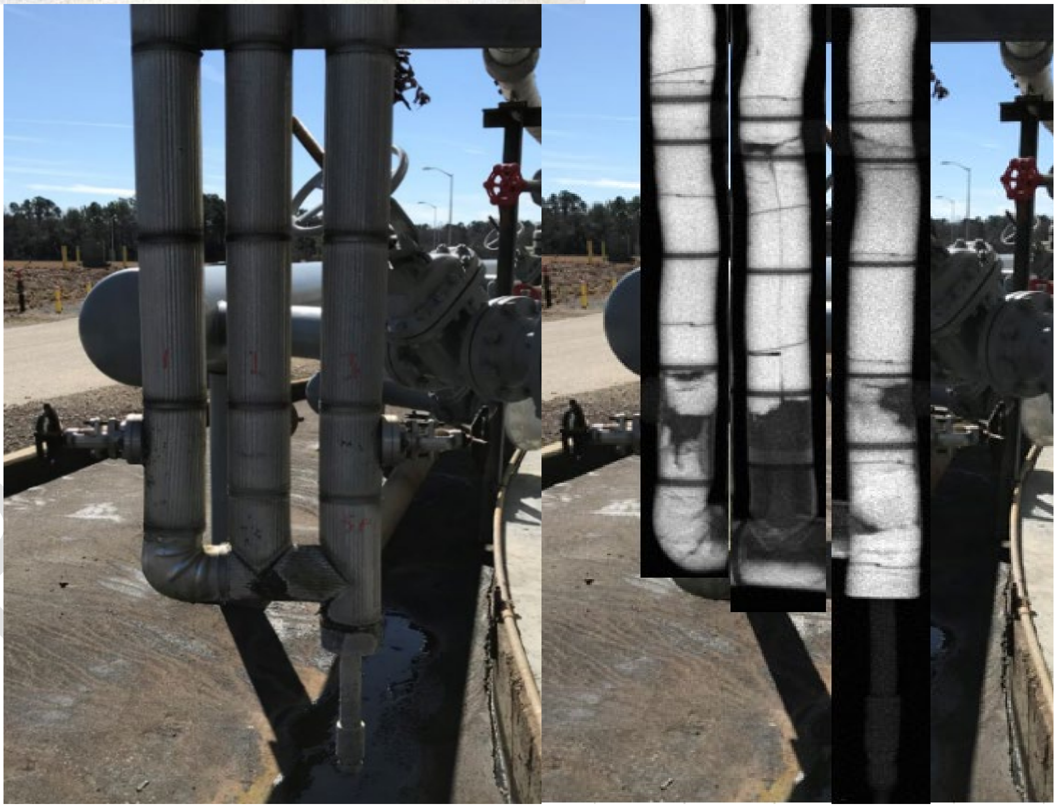
Figure 28 shows the MDI instrument in use and examples of the data display of what these suspect areas could resemble. These images show only detection of moisture under the insulation and not noted CUI damage by this representation alone and without the aid of furthermore quantitative follow-up.

Capabilities and limitations for MDI are identified below.

- a) Capabilities
  - 1) Can detect water in insulation and depending upon the thickness, fireproofing material.
  - 2) Does not detect corrosion itself but identifies areas of concern to deploy other more quantitative NDE techniques.
  - 3) Can be utilized on piping, tanks, vessels, and other equipment configurations.
  - 4) Can be utilized on complex geometries, however, will be hindered where device does not have proper line of sight to the testing surface
- b) Limitations
  - 1) Temperature limitation should be considered in terms of the test specimen and the susceptibility of moisture accumulation based on the in-service operating temperature.
  - 2) Highly useable on complex geometries if line of sight from the instrument to test surface is unobstructed. Structures like support etc. could hinder the view of the MDI device causing loss of or improper and unreliable results.
  - 3) Dense material like cementitious fireproofing could hinder X-ray transmission.
  - 4) Detects the presence of water or hydrocarbon in the insulation system, not corrosion; technique is only effective while insulation is wet; technique is not effective if sufficient time has elapsed for insulation to dry out.

~~The moisture detection imaging (MDI) is a Compton backscatter technique, as X-rays hit an object, some are absorbed, producing a transmission X-ray image, and others are "scattered" (Compton scattering). Backscatter images are formed from the X-rays that are scattered back toward the X-ray source and the collection detector. Compton scattering is material-dependent, with the lower atomic number materials scattering more strongly than the higher numbered ones. Examples are shown in Figure 24.~~

~~It should be noted that this technique detects organic compounds. Therefore, this device cannot distinguish between water, hydrocarbons, acids, bases, and organic liquids. However, the presence of any of these fluids would warrant follow-up inspection.~~



Example areas of wet insulation

Area of missing insulation

Insulated System

MDI Image (Wet Insulation)

Figure ~~24~~28—Examples of Inspectors Working with the Tool (top image); for the bottom images,

the Left-hand Side Shows a System and the Right-hand Side Shows the Corresponding MDI Response

~~Advantages and disadvantages for the MDI inspection method are as follows.~~

~~a) Advantages:~~

  ~~1) detects the presence of water or hydrocarbon under insulation jacketing;~~

  ~~2) easy-to-use method that can be used to rapidly scan insulated surfaces;~~

  ~~3) low-energy source;~~

  ~~4) only requires access to the surface.~~

~~b) Disadvantages:~~

  ~~1) detects the presence of water or hydrocarbon in the insulation system, not corrosion; technique is only effective while insulation is wet; technique is not effective if sufficient time has elapsed for insulation to dry out.~~

7.3.3.7 Through Transmission Field Measurement Method (TTFM)

TTFM is a semiquantitative, non-contact method to detect corrosion or wall loss defects in a ferrous material. An exciter coil is energized with a low frequency alternating electric current which has a magnetic field which couples to the ferrous metal component of the material. This induces eddy currents in the part which in turn generate their own magnetic fields. An array of sensors measures the phase angle and field strength of the induced eddy currents which is related to the wall thickness of the part.

TTFM probes produce a magnetic field and eddy currents that travel through the component wall and, depending on the application, are detected either on the far side or near side of the component wall. The through transmission field in a typical pipe is shown in Figure 29.

TTFM can be delivered manually or semi-automated (with encoded distance). For a sphere leg or other vertical orientation, a separate drive mechanism can be attached for automated delivery.

TTFM can detect corrosion of insulated or fireproofed metal pipes, tanks, vessels, and structures. It discriminates near-side defects only (i.e., OD wall loss) on insulated equipment but can penetrate up to 0.5” on bare pipe or plate. ~~ToD~~Detection threshold ~~(threshold of detection)~~ is a function of insulation thickness only as shown in Table 20.

Table 20— ~~ToD~~Detection Threshold for Local and General Wall Loss

CUI Local Wall Loss	CUI General Wall Loss
Ø0.5” dia. 20% deep FBH at 1” insulation Ø1.0” dia. 20% deep FBH at 2” insulation Ø2.0” dia. 25% deep FBH at 3” insulation Ø2.0” dia. 30% deep FBH at 4” insulation FBH = flat bottom hole	10% deep wall loss or more

The TTFM method (using the medium array) can inspect approximately 6 linear ft/min (2 m/min). This equates to 1.5 ft/min (0.5 m/min) for full circumferential coverage of an 8” pipe with 2” insulation. Scan speed is independent of wall thickness. Probability of Detection (PoD) for 10” sch 80 pipe with 4” insulation is 0.5 for 25% wall loss and 0.9 for 35% wall loss. Small and medium arrays may require only a single technician. Figure 30 shows a medium array bracelet for pipe. Depending on work environment (elevated piping, scaffolding location, etc.) and equipment size (large vessels, long pipe runs or sphere leg inspections), additional personnel may be required for efficiency. Figure 31 shows a TTFM examination of an insulated pipe.

For the best results, a constant liftoff distance should be maintained. Where there is damaged jacketing or sagging insulation, the detection sensitivity can be affected due to varying distance from the inspection material.

Data from the TTFM probe/array is fed to a laptop computer which both displays and instantly records the O.D. condition of the pipe under the insulation. Raw data trace (strip chart), C-scan, and voltage plane information can be displayed in real time and recorded. Screen images of the data are used to size the detected defects. Figure 32 shows an example data output from an examination of an LPG sphere leg.

Capabilities and limitations for TTFM are identified below.

- a) Capabilities
  - 1) Detects both general and localized wall loss
  - 2) Can be performed on smooth and corrugated jacketing material.
  - 3) Can be performed at surface temperatures between -238 °F and 932 °F (-150 °C and 500 °C). Note: hot surfaces require insulation
  - 4) High sensitivity to small volume defects at challenging locations like pipe supports and support rings.
  - 5) Can inspect typical pipe component configurations and geometries.
- b) Limitations
  - 1) Areas close to protruding features (nozzles, branch connections, support rings, etc.) cannot be scanned since the sensors are set back from the edge of the array. A smaller array, however, is able to scan closer to the protrusions.
  - 2) Limited to ferromagnetic materials (e.g. carbon steel, Cr-Mo steels, etc)
  - 3) Jacketing material has to be non-ferromagnetic (stainless steel or aluminum).
  - 4) Minimum diameter is 6” including insulation or fireproofing thickness for the medium array. No minimum diameter for the small array.
  - 5) Cannot detect small pitting unless grouped in an area exceeding the surface area limit shown in Table 20 above.

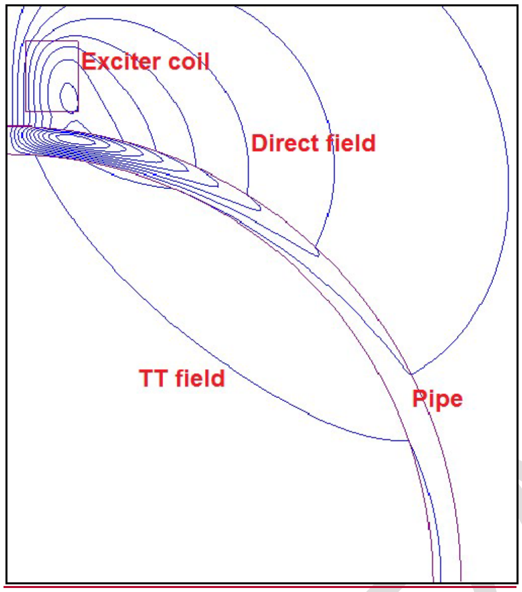


Figure 29—Through Transmission Field in a Typical Pipe

Figure 30—TTFM Medium Array Bracelet

Figure 31—TTFM on Insulated Piping (Medium Array)

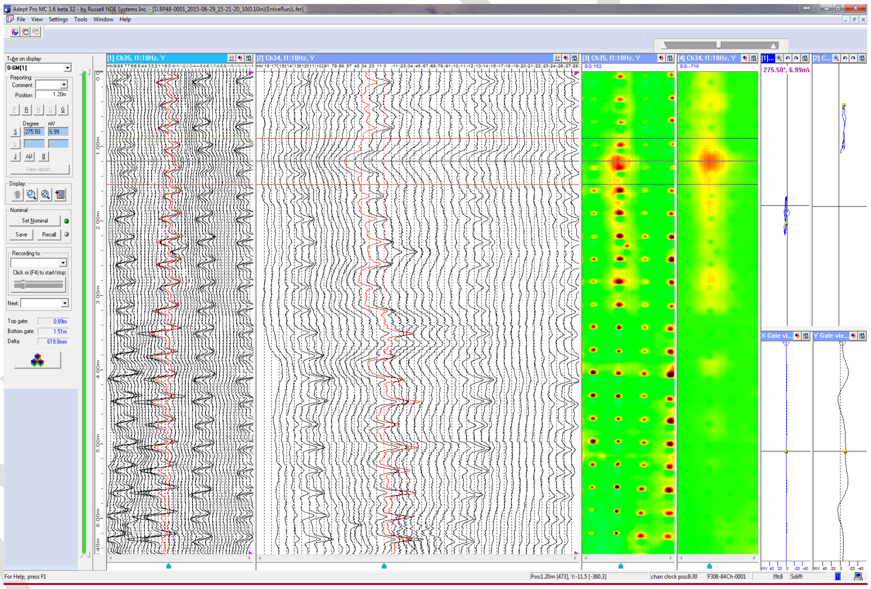


Figure 32—TTFM Graphical Representation of Sphere Leg with Fireproofing Anchors

7.3.3.3 Ultrasonic In-Line Inspection ~~(UT-ILI)~~

A quantitative inspection technique for CUI metal loss from the interior of the pipe or pipeline using an in-line inspection (ILI) system is comprised of an inspection tool, also called an intelligent or smart pig, associated hardware, software, procedures, and qualified personnel for performing and interpreting ILI results. The ILI inspection tool can be, for example, tethered devices, self-propelled robotics, or free flowing inspection tools.

~~UT~~ ILI inspection tools, utilizing an immersion pulse echo technique, can quantify both wall thickness and geometrical measurements in piping systems. These inspection tools are outfitted with numerous ultrasonic transducers, or an individual rotating sensor, to permit ultrasonic longitudinal wave sampling for the detection and quantification of internal and external metal loss (general and localized), manufacturing defects, and geometrical deformations.

The piping characteristics often determine the feasibility of an ILI inspection. Launching and receiving devices need to accommodate the physical attributes of the ILI tool and are usually temporary components of the piping systems. Many ILI systems allow for bi-directional launching and receiving capabilities that permit single point entry into the pipe. The internal bore of the piping needs to be large enough to allow safe passage of the ILI system tool. The piping configuration and fittings can affect the feasibility of some ILI systems. The ability to properly prepare internal surface by removing internal debris and scales that would impede the ultrasonic signal with cleaning pigs and/or scraper devices.

Owner-operators should evaluate and understand the ILI system's performance capabilities and limitations to ensure it will meet their objectives. Figure 33 shows a typical ILI process flow diagram. A performance specification should define the ILI system's capabilities to detect, quantify, classify, locate and characterize the anomalies and features expected within the pipe and it should be validated through a qualification process. Evaluation and selection of an ILI system should also include:

- the inspection coverage obtainable. Inspection coverage is related to the number of transducers inherent to the inspection tool, its travel speed, and the piping diameter being inspected. For instance, a localized CUI damage may require 100% coverage from an ILI technology to confidently detect and quantify the feature.

- the sensitivity obtainable. The minimum detectable anomaly size for the ILI tool should be optimal for the expected size of the piping anomaly to be detected. Special consideration should be given to the ultrasonic transducer's resolvable capabilities as it relates to its frequency, diameter, stand-off, and ultrasonic beam spread.

- the probability of detection. A statistically derived capability to detect specific features and sizes of features in piping systems. The sizing and characterization accuracy of anomalies should be sufficient to enable evaluation, and when applicable, remaining strength determination. Detection and sizing thresholds should include minimum depth, length, width, and reduction in cross section or diameter as applicable to each feature. The location accuracy, or distance and orientation accuracy, of features should enable ease of locating detected features.

- The probability of identification. A statistically derived capability to correctly differentiate and identify detectable anomalies and features. Types or characteristics of anomalies and features should be correctly classified as to the identity of the indication.

The operational reliability and confidence of the ILI system and the ILI vendor's capabilities should include evaluating the history of the ILI system performance through experience and validations. The ability of the ILI system to collect valid data through the full length and circumference of the piping system should be evaluated along with the ILI vendor's previous success rates and failed surveys.

Data/Results provided by ILI systems typically include a feature spreadsheet, inspection report, and data set with software viewer. ILI systems typically provide a high confidence level and deliver a qualitative and direct measurement capability. A validation and verification process should be considered to ensure the inspection results meet or exceed the performance specifications of the ILI technology.

Refer to API Standard 1163 and NACE SP0102 for additional information regarding ILI inspections. In addition, refer to ASNT Standard No. ILI-PQ, for minimum qualification and certification requirements of personnel analyzing and interpreting ILI information.

Capabilities and limitations for ILI systems are identified below.

a) Capabilities
  1) Detection and sizing of general and localized corrosion / wall loss, and isolated scabs from CUI of piping
  2) Detection and sizing of internal metal loss, of deformations and mechanical damage to the pipe.
  3) Insulation and/or coating type and thickness typically do not have an adverse effect on the ILI results.
  4) Can inspect piping diameters between 2” NPS through 48” NPS
  5) Wall thickness detection range can vary between 0.050” through 2.000”.

b) Limitations
  1) The cleanliness of the piping system should be reviewed as internal fouling may prohibit ultrasound transmitting into the piping wall and adversely affect the data quality and tool wear.
  2) Ultrasonic immersion technique requires a liquid medium to transmit ultrasonic energy.
  3) Ultrasonic longitudinal waves cannot detect cracks or crack-like features.
  4) Piping systems may need to be inspected when off-line.
  5) Temperatures greater than 150F and less than 32F need evaluation.
  6) Access and navigation may prevent use of some ILI tools.

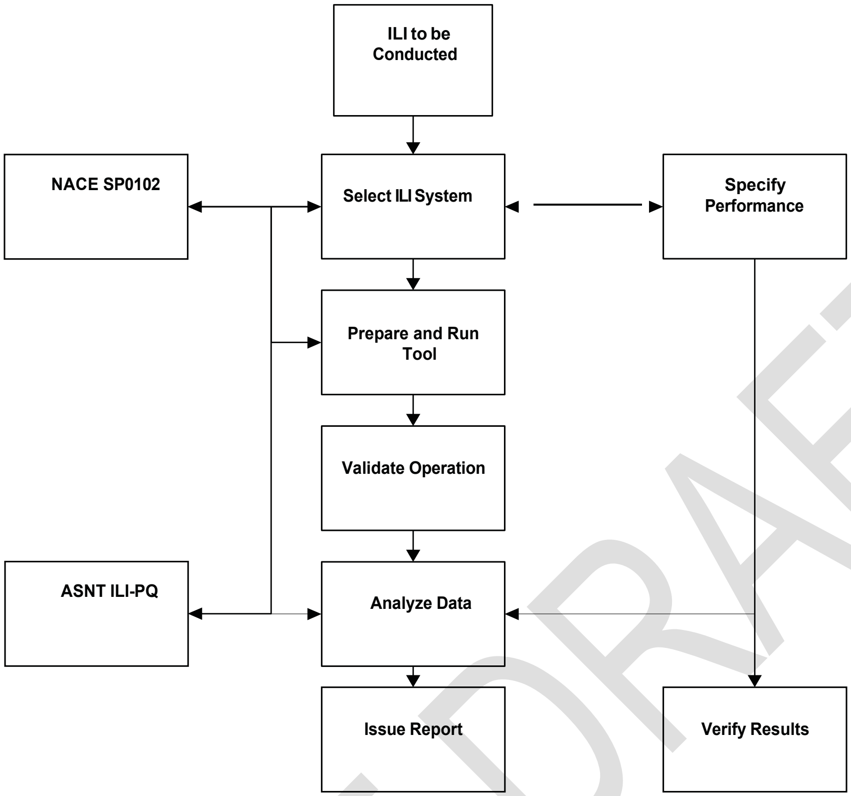


Figure 33 In-line Inspection Process Flow Diagram

7.3.3.4 Continuous Monitoring Devices for CUI Applications

Continuous monitoring utilizing permanently installed detector systems may assist in reducing the need for extensive inspection. Various systems are used to quantify and monitor conditions below insulation. Some example systems include:

- Guided wave through sensors
- Humidity monitors
- Liquid water detectors
- Fiber optic sensing

Data from these systems can be used to generate a risk factor based on industry standards.

While these systems do not decrease the inherent risk of CUI/CUF, they alert inspectors to areas of potential damage by monitoring the conditions between the insulation system and the asset for corrosive environments. These devices provide real time information on various conditions that affect the likelihood of CUI/CUF. Monitored conditions include, for example, humidity, liquid water presence, temperature, and corrosivity. Detection thresholds vary based on the specific system utilized.

Depending on the specific system, sensors are installed on the equipment surface, penetrating through the insulation jacketing, or laying on-top of the jacketing.

When used appropriately, online monitoring for CUI/CUF can focus inspection efforts. These systems may rule out equipment and piping for CUI inspection by showing where water has not ingressed. They may provide early detection for equipment at risk for CUI/CUF so that intervention can be made before excessive damage occurs or identify areas that need accelerated intervention due to excessive exposure to conditions that promote CUI.

Effective use of monitoring systems requires integration into existing integrity programs. Important aspects that should be considered are:

1) Data management – The quantity of data generated by continuous monitoring is much more than traditional methods of inspection and visual monitoring. Infrastructure and workflows may need to be created to ensure that this information is used effectively, and decisions can be made by the right people.
2) Sensor application – most technologies in the CUI/CUF monitoring space are relatively new (<10 years old). Each technology has use cases that optimally weigh their inherent advantages and disadvantages. Owner/operator guidance on the applications and limitations of these technologies may be beneficial to help ensure they are appropriately used and avoid over-reliance on monitoring data. While monitoring may provide data that eliminates the need for full insulation/fireproofing removal for visual examination or other NDE techniques, the presence of the sensors does not inherently insure proper data collection and interpretation.

Capabilities and limitations for continuous monitoring systems are identified below.

a) Capabilities
   1) These systems predict general and localized corrosion from CUI by monitoring for conditions that promote CUI.
   2) Can be used on both piping and vessels of any size
   3) Challenging locations and complex geometries can cause different responses to sensors depending on the technology implemented (sensor location relative to the insulation system).
   4) Most technologies are coating and insulation system agnostic

b) Limitations
   1) To date, continuous monitoring has only been done under insulation. However, some technologies may be adaptable to under fireproofing applications with additional development and testing Temperature limitations vary based on specific technology
   2) Some systems require insulation to be removed. Access requirements are the same as replacing insulation.
   3) Systems do not monitor the asset for wall loss; only determine changing risk factors based on changing conditions

8 Design Practices to Minimize CUI

8.1 General

The design of hot and cold service insulation systems has to address certain specific requirements. Three of these requirements are common to both services and relate to coating of the substrate metal, selection of the insulation material, and weatherproofing. A further requirement is the necessity for a vapor barrier in cold service.

A properly installed, sealed, and maintained insulation system is the first step at preventing water ingress into the system and reduces the risk for corrosive conditions. However, when the weather barrier fails, wet environments that are favorable for CUI can develop. It is important to evaluate each component of the system and the system as a whole to provide proper installation and maintenance to prevent CUI. Not one approach will be the answer to CUI mitigation. Multiple approaches ~~must~~ have to work together to prevent ~~battle~~ corrosion.

8.2 Coatings for Hot and Cold Services

The coating system provides protection from corrosion when water penetrates the insulation system. The coating system needs to be capable of operation under intermittent ~~immersion~~ service. Intermittent service is defined in many owner-operator specifications ~~from major petroleum and petrochemical companies~~ as 15 % of time spent in the temperature range of risk. Equipment that operates or stands at ambient temperature for more than 15 % of its expected life should also be coated.

Carbon steel should be coated with an immersion grade coating, which should be used up to the maximum temperature limits recommended by the manufacturer of the particular product. It should be emphasized that the coating manufacturer's application instructions be strictly followed to optimize coating performance. This includes such conditions as relative humidity/temperature limitations, standards of surface preparation, and the length of time between priming and topcoating to prevent intercoat adhesion difficulties. Within the past several years, numerous ~~owner/user~~owner-operators have specified the application of TSA to reduce the potential for corrosion in applications prone to CUI damage. As with any applied coating, surface preparation and application concerns need to be addressed to maximize the service life of the coating (see 11.5).

In some applications, additional measures may be taken to prevent corrosion and cracking of the base metal.~~If special protection is required, the surface should be degreased and then coated.~~ Water glass (sodium silicate) is used to coat the surface when inhibited calcium silicate is the specified insulation material. A silicone-acrylic coating (guaranteed free from low melting point metals, e.g. zinc) is used when foam glass, mineral wool, etc., are the specified insulations. For stainless steel equipment, some owner-operators specify wrapping the equipment with aluminum foil prior to insulating for additional protection by acting as both a physical and a galvanic barrier to prevent ECSCC.

8.3 Insulation Materials

8.3.1 General

For both hot and cold service, the nonabsorbent type of insulation is a popular choice if the application is within its limits. Nonhydrophobically treated mineral wool, fiberglass, and non-water-resistant calcium silicate have the highest tendency to absorb water and therefore a higher susceptibility to CUI damage. Materials with a closed-cell structure or homogenous water-resistant properties such as expanded perlite, water-resistant calcium silicate, water-resistant mineral wool, silica aerogel flexible blanket, microporous flexible blanket, and cellular glass tend have a higher resistance to absorbing water (except at low points due to immersion conditions) and will help minimize the risk of CUI. Insulating coatings do not absorb any water and mitigate the risk of CUI.

Common insulation systems for hot and cold services are outlined below. The lists shown below are not meant to indicate that these are the only materials that can be used in the services and temperature ranges. Owner /users may wish to review the advantages and disadvantages of insulation materials listed in Section 6 prior to selecting an insulation material for various applications. Alternately, ~~owner/user~~owner-operators may prefer to consult a subject matter expert to develop guidelines on the applicable insulation materials for specific service.

8.3.2 Ferritic Steel in Hot Service

Examples of insulation materials used on ferritic piping or equipment in hot service are ~~shown~~ identified below.

- Up to 200 °F (93 °C): Cellular glass, expanded perlite, calcium silicate, microporous blanket, silica aerogel, mineral wool, fiberglass, polyurethane foam, polyisocyanurate foam, elastomeric foam or insulating coatings.

— Over 200 °F (93 °C) to~~but under 250~~ 300°F (~~121~~149 °C): Cellular glass, expanded perlite, calcium silicate, microporous blanket, silica aerogel, mineral wool, fiberglass, polyisocyanurate foam, elastomeric foam or insulating coatings, up to their limits.

— Over ~~250~~300 °F (~~121~~149 °C): Cellular glass, calcium silicate, microporous blanket, silica aerogel, mineral wool, fiberglass, or insulating coatings, up to their limits.

8.3.3 Ferritic Steel in Cold Service

Examples of insulation materials used on ferritic piping or equipment in cold service as low as –76 °F (–60 °C) - are~~: shown below.~~

— ~~–76 °F (–60 °C) to 800 °F (427 °C):~~ Cellular glass,

— silica aerogel.

— ~~–76 °F (–60 °C) to 200 °F (93 °C):~~ Polyurethane foam,

— ~~silica aerogel.~~ Polyisocyanurate foam

8.3.4 elastomeric foamAustenitic/Duplex Stainless Steel in Hot Service

Examples of insulation materials used on austenitic or duplex stainless steel piping or equipment in hot service are shown below.

— Up to 400 °F (204 °C): Cellular glass, expanded perlite, calcium silicate, microporous blanket, mineral wool, fiberglass, silica aerogel.

— Over 400 °F (204 °C): Mineral wool and fiber glass (up to limit), expanded perlite, calcium silicate, microporous blanket, or silica aerogel.

8.3.5 Austenitic/Duplex Stainless Steel in Cold Service

Examples of insulation materials used on austenitic or duplex stainless steel piping or equipment in cold service are shown below.

— to –436 °F (–260 °C)~~ to 800 °F (427 °C)~~: Cellular glass, ~~or~~ silica aerogel, polyisocyanurate foam.

— to –260 °F (–162 °C~~) to 200 °F (93 °C)~~: Polyurethane foam,~~ or silica aerogel~~.

8.3.6 Vapor ~~Barrier~~Retarder

Insulation material in cold service applications needs a~~A~~ continuous vapor retarder~~barrier~~ installed over it to help prevent water ingress, condensation and possible ice formation on the metal surface depending upon the surface temperature.~~ is required for cold service applications.~~ There are~~is~~ several types of vapor retarders. ~~barrier should be continuous and is usually~~ A common one is a ~~provided by a~~ glass fiber-reinforced mastic installed by applying a layer of mastic, wrapping with a glass-fiber mesh, and covering with another layer of mastic. ~~impregnated with three coats of an elastomeric material~~. Other types of vapor retarders include butyl rubber membranes and PAP, polyester, and polyvinylidene chloride (PVDC) films. This elastomeric material should be compatible with the insulation material and flexible at the lowest expected ambient temperature. If it is to be left uncovered (i.e. unprotected by metallic weather proofing), the vapor retarder~~barrier~~ should be resistant to solar radiation.

8.4 Jacketing

8.4.1 ~~General~~Materials

Jacketing materials fall into two general categories, namely:

- metallic jacketing, and
- nonmetallic jacketing.

Metal jacketing is the most common jacketing material for insulation. Jackets should be designed so that all joints are in the watershed position. Adequate overlaps should be employed to protect against opening due to thermal expansion and contraction of the pipe and insulation.~~coupled with the use of ~~E~~e~~lastomeric sealants are used to to prevent ingress of water either by gravity, by capillary action, or by wind drift~~.~~ at penetrations in the insulation and at terminations.

Metallic jacketing materials include aluminum, steel, and stainless steel.

Nonmetallic jacketing materials such as mesh-reinforced CSPE and UV curing GRP are designed to prevent water ingress as a method to prevent CUI. Nonmetallic systems are resistant to mechanical damage.

8.4.2 Penetrations in Jacketing

~~8.4.1.1~~8.4.2.1 Nozzles and Attachments

The areas of concern on an insulated, vertical vessel are illustrated in Figure ~~25~~34. As indicated, the top head especially where nozzles, lifting lugs, etc. project through the insulation can be at greatest risk from CUI. Similarly, the vertical walls are at risk at positions where horizontal attachments (support brackets, stiffener and/insulation rings, nozzles) pierce the insulation. Such attachments can provide paths for water to short circuit the weatherproofing/insulation and contact the walls.

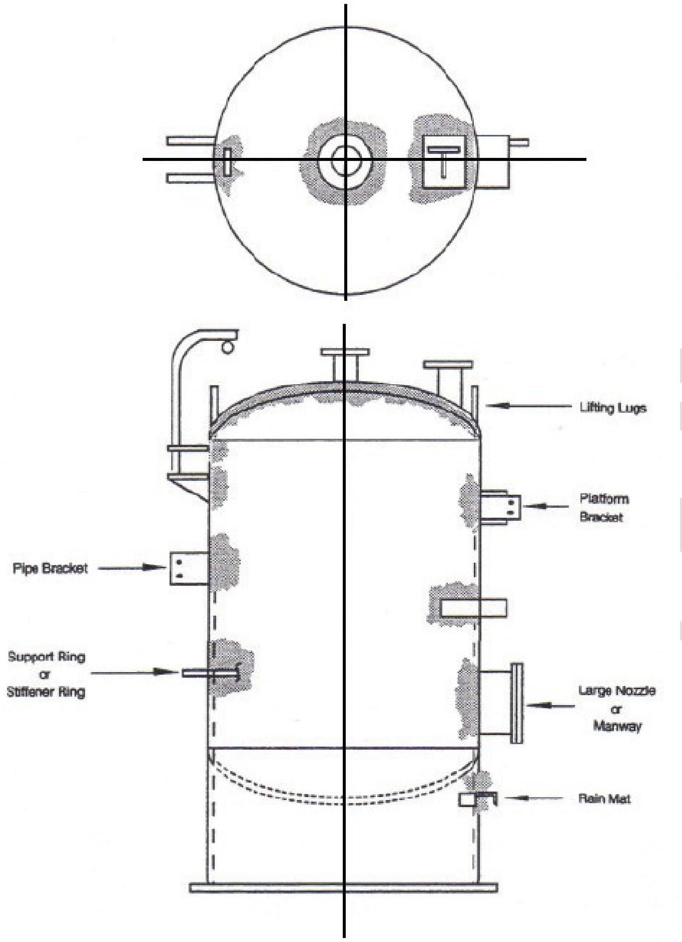


Figure ~~25~~34—Areas of Concern for CUI in a Vertical Vessel

~~8.4.1.2~~8.4.2.2 Appurtenances

Vessels, exchangers, tanks, and piping include a number of appurtenances that are required for support, reinforcement, and connection to other items. Details such as gussets, brackets, reinforcing pads, saddles, support shoes, vacuum rings, etc. fall into this category. These appurtenances make weatherproofing difficult as they provide preferential channels for the entry of water into the insulation. Needlessly complicated support details are difficult to insulate correctly, and insulation workers often seal these areas poorly unless closely supervised during insulation installation.

~~8.4.2~~8.4.3 Jacketing~~Insulation~~ Laps ~~and Folds~~

Jacketing should be installed in such a way as to eliminate water ingress. This includes sealing any breaks or penetrations in the sheeting using a silicone caulking material and locating the jacketing ~~folds and~~ overlaps in such a way that moisture cannot be trapped by the jacketing. Namely, laps~~folds~~ in the jacketing on horizontal piping need to be located between the 4 o'clock and 8 o'clock position. On vertical piping, laps~~folds~~ in the jacketing need to be located on the side away from the prevailing winds. Of course, jacketing joints need to be installed so that water tends to run off, rather than underneath, the joint.

~~8.4.3~~8.4.4 Corrosion of Metal Jacketing

Sometimes metal jackets suffer from underside corrosion in hot service. This is due to water vaporizing after being trapped in the insulation during ~~the insulation operations~~installation or entering the system during normal service.~~ becoming vaporized~~. The vapor is driven to the jacket where it condenses to form alkaline or acidic solutions, depending on the insulation type. The cycle repeats and the corrosivity of the condensate increases and results in the corrosion of the aluminum or steel jacket. Metal jackets should contain moisture barriers on the inside. Where corrosion of the jacket has traditionally been a problem, ~~plastic or all-weather~~non-metallic jacket types may provide a solution.

~~8.4.4~~8.4.5 Techniques to Minimize Water Ingress

~~8.4.4.1~~8.4.5.1 General

Examples of insulation techniques that can be adopted to minimize the possibility of water ingress at ~~such~~ attachments are shown for vessels and piping components in Annex B. In essence, all the techniques are based on preventing water breaching the external weatherproof covering. This primary objective is then further reinforced by the provision of secondary measures. Some of t~~T~~hese measures for cold systems can include ~~, which include~~ the use of vapor retarders~~barriers~~ and/or staggering joints in multilayer insulation systems. These measures can be beneficial ~~with staggered joints, are important~~ if the external weatherproof is breached.

If corrosion is to be prevented, attention should be given to the design and the installation of the insulation system and to the provision of suitable barriers to water ingress. These barriers should eliminate crevices that permit the concentration of moisture and chlorides. To this end, welded external attachments should be minimized. If these are unavoidable, welds should be continuous, and the entire equipment should be protected with suitable barrier coatings. The primary safeguard against CUI is a continuous weatherproof barrier. Special attention should be paid to the application of insulation, in particular to the weatherproofing, around projections such as nozzles and clips because these offer ready paths for water to enter and migrate to the surfaces of the underlying metal. Consideration should be given to the use of nonmetallic jacketing to fully waterproof the insulation.

~~8.4.4.2~~8.4.5.2 Insulation Jacketing Drains ~~Holes in Jacketing~~

~~Small [e.g. $^1/_4$ in. (6 mm)] diameter drain holes can be drilled in rigid insulation~~Low point drains can be installed on insulated hot piping to allow any water accumulating in the insulation to escape. Low point ~~D~~drains ~~holes~~ should be located at the bottom of vertical piping runs and along the bottom of horizontal piping; at a minimum there should be one low point drain ~~hole~~ per pipe support span. Low point drains are typically small [e.g. $^1/_2$ in. (12 mm) to 1 in. (25 mm)] diameter weep holes in insulation. Water detectors can be installed at those positions to indicate the presence (drainage) of water and the opportunity to analyze the collected water for corrosion product content (i.e. indication of coating breakdown).

8.5 General Design Aspects

8.5.1 General

One of the ~~prime~~ objectives ~~of~~ in the general design of equipment and piping ~~that is~~to be insulated should be to minimize CUI.

8.5.2 Design Simplification

As a general rule of thumb, complicated designs are difficult to insulate and should be avoided. Figure ~~26~~ 35 is an example of a design layout that is difficult to insulate and weatherproof and therefore has from the outset a high potential for CUI.

Figure ~~26~~35—Example of a Design/Layout That Is Difficult to Insulate

8.5.3 Pressure Vessels

For the purposes of this document, “pressure vessels” include all major types of static equipment (e.g. columns, heat exchangers, etc.). Design considerations for pressure vessels include the following.

a) The design and orientation of any protrusions should be configured to aid effective water shedding.

b) If possible, seal-welded sealing discs should be installed on vessel nozzles and other protrusions through the insulation. Seal-welded plates are useful in diverting water away from critical locations. These can be used, for example, on nozzles for vessel shells and tank roofs to divert water away from the protrusion through the jacketing. However, this requires attention to design detail, particularly for horizontal protrusions. An example of sealing discs on vessel nozzles is given in Figure B.6.

c) To aid insulation fit-up and the achievement of a watertight seal, attachments supporting ancillary items such as ladders, gantries, etc. on insulated vessels should be of a sufficient length such that they protrude beyond the insulation thickness by at least 100 mm (4 in.) when measured perpendicular to the surface of the insulation.

d) Nozzles and manways should be at least 76 mm (3 in.) longer than the insulation thickness to allow for the insulation and jacketing to be terminated and sealed independently of the nozzle flange insulation and to give proper clearance for flange bolt withdrawal without damaging the nozzle insulation.

e) Bucket-type insulation support rings (as described in NACE SP0198), which could act as a moisture trap, should be avoided.

f) If installed bucket-type insulation support rings should be drilled to allow water to escape (note that maintaining rust-free drain holes is a long-term maintenance issue).

g) ~~If practicable, I~~insulation support rings should be attached to brackets that are seal welded to the vessel shell in such a way that there is a gap between the support and the shell. An example of such a support is given in Figure B.7.

~~h) Nameplates.~~

~~i)~~h) Attaching n~~N~~ameplates to~~on~~ insulated vessels should be designed so that the bracket is oriented to avoid trapping water against the shell and allow the weather jacketing to be properly sealed behind the plate.~~should be fully incorporated in the insulation.~~

~~1) Duplicate nameplates should be prepared and attached to the pressure vessel. Duplicate nameplates should exactly reproduce the layout and information content of the original. The location and method of attachment of the duplicate to the outside of the insulation may vary depending on the vessel layout.~~

8.5.4 Piping

8.5.4.1 General

Design considerations for piping include the following.

a) Supports for insulated piping should, if possible, make use of load-bearing insulation/jacketing to allow the pipe to be supported without the need to penetrate the insulation. If load-bearing insulation/jacketing cannot be used, the minimum length of the support should be four times the insulation thickness. Pipe supports are difficult to seal, and the above modification enables the insulation jacketing to be continuous beneath the support clamp.

b) Water hoods should be fitted to vertical overhead pipe supports to direct water away from potential entry points where the support penetrates the insulation.

c) Separation distances for insulated piping should be 1.5 times the sum of the insulation thicknesses to be applied to the pipes. For example, the minimum pipe to pipe separation of two lines the first with 4 in. (100 mm) of insulation and the second with 1.2 in. (30 mm) should be (4 in. + 1.2 in.) × 1.5 = 7.8 in. or (100 mm + 30 mm) × 1.5 = 195 mm.

d) Separation distance between insulated piping and from structural steelwork should be two times the insulation thickness.

e) If possible, ~~dead-legs~~deadlegs in insulated piping should be avoided. Piping ~~dead-legs~~deadlegs can be particularly prone to CUI. Heat leaking into ~~dead-legs~~deadlegs in cold piping or heat loss leading to cooling of ~~dead-legs~~deadlegs in hot piping can bring the effective operating temperature at the ~~dead-leg~~deadleg into a range in which the risk of CUI is much higher. Considerations should be given to whether or not insulating ~~dead-legs~~deadlegs could cause internal corrosion such as dew point corrosion.

f) Heat tracing.

   1) If insulated piping is steam traced, joints in steam-tracing pipework should be located outside the insulation jacketing. Steam-tracing pipework should enter and leave the insulation at the lowest possible point. Steam leaks often occur at joints in the tracing pipework. If the joints are inside the insulation, leaking steam can rapidly saturate the insulation and promote very rapid corrosion.

   2) Electric heat tracing should be permanently fixed to the pipe independent of the insulation material.

   3) Penetrations of electric heat tracing tape through the jacketing should be fitted with appropriate cable grommets or glands to prevent moisture ingress. The penetrations should be positioned away from the prevailing weather and between the 4 o'clock and 8 o'clock positions on horizontal pipe.

8.5.4.2 Valves and Instruments

Design considerations for valves and instruments include the following.

a) Valves and instruments such as pressure and temperature gauges in insulated piping should have stems of length equal to at least twice the thickness of the insulation.

b) If insulation will be frequently removed for maintenance or inspection (e.g. at relief valves), the insulation on the pipework should be terminated and capped at a location that allows flange breaking without interference with the sealed cap. Insulation and jacketing of isolation and relief valves should be independent of pipe insulation.

8.5.5 Tankage

Design considerations for tankage include the following.

a) Roof overhang on fixed roof tanks: On a tank that is to be insulated the tank roof should overhang the shell by at least the shell insulation thickness plus 2 in. (50 mm). This is to direct water running off the tank roof away from the insulation. If the tank roof is also insulated, it helps prevent any moisture that has gotten into the roof insulation from passing down into the insulation on the shell.

b) Ancillary attachments to tank shells and roofs:

    1) ancillary attachments such as ladders, stairways, level controls, etc. should have a standoff of at least four times the insulation thickness;

    2) for roof-entry pipework supports, the pipe standoff should be a minimum of 6 in. (150 mm) greater than the combined thickness of the insulation on the tank shell and the insulation thickness on the pipe.

c) Double shell insulated tanks: Double shell insulated tanks should be designed in such a way as to prevent moisture getting into the void space. Double shell insulated tanks have the insulation installed in the void space between the two shells.

8.5.6 Small Bore Pipe and Fittings

Small bore pipe and fittings can be particularly vulnerable to CUI because the wall thicknesses required for pressure containment are small. Increasing the thickness of carbon steel small bore piping to provide a corrosion allowance can add a safety factor, but it does not prevent CUI and does not remove the need to inspect for CUI. Some sites use stainless steel for thin wall small bore piping and fittings.

8.5.7 Other Concerns

8.5.7.1 Shelters from Prevailing Weather

If there is a high concentration of insulated pipework and equipment in a small area in a location where precipitation is likely to be frequent, a permanent shelter should be considered to be erected around the plant to protect the insulated area from the weather. If rainfall is a regular feature of the local climate, then insulated equipment enclosed in weatherproof shelters is less likely to suffer from CUI.

8.5.7.2 Walkways

Steps and/or bridges as appropriate should be provided to allow personnel to cross low-level pipe tracks without stepping on insulation. Damage to insulation caused by foot traffic on insulated piping can be an entry point for moisture and has been a major contributor to increasing the likelihood of CUI.

8.6 Insulation

Design considerations for insulation include the following.

a) Insulation materials should be installed in such a manner that the external surface should be as uniform as possible and that the jacketing is applied and sealed properly.

b) Consider the use of standoffs or a noncontact system between the insulation and the piping or vessel surface when fibrous insulation materials are used in areas with a potential for CUI in order to keep wet insulation from direct contact with the insulated surface.

c) Some insulation materials have coefficients of linear expansion that are significantly different than steel. The insulation system design should consider the installation of expansion and contraction joints to accommodate the difference in expansion coefficients.

d) Parts of the insulation system intended to be removed and replaced during unit operations, such as valve boxes, need to be designed to undergo multiple removal/replacement cycles.

8.7 Heat-traced Systems

Steam-tracing systems are manufactured using carbon steel, copper, stainless steel, or nickel-based (i.e. Incoloy) tubing materials. Though nickel-based tubing materials are expensive, they have a lower probability of in-service failure and may be justified on high-criticality systems. At many sites, nickel-based tubing materials such as Incoloy 825 are considered as standard for instrument systems where they are economic or risk appropriate.

When extensive insulation removal is planned for a steam-traced system, consideration should be given to renewing the associated tracing with tubing couplings/joints outside of the insulation, or replacement with an electric-traced system.

8.8 Protective Coatings and Caulk

8.8.1 General

The primary element in preventing CUI damage is to keep moisture from reaching the surface of the insulated component. This can be achieved by either:

a) the application of coatings to the surface of the component, or

b) preventing moisture from penetrating the insulation system.

A well-designed coating system applied to the surface of a component prior to insulation, together with a properly insulated system, can provide greater resistance to CUI damage and reduced maintenance costs. In addition to the benefits associated with the application of a protective surface coating system, the application and maintenance of insulation jacket caulking to metal jacketing or the adoption of a nonmetallic system are critical components of preventing moisture from breaching the insulation system.

8.8.2 Coating Considerations

A coating system should protect against water or corrosives for long periods. Highly permeable organic coatings allow corrosion to start behind the coating even in the absence of breaks or pinholes. As a result, organic coating systems that are suitable for immersion service are usually preferred where there is a potential for CUI damage. Typically, a two-coat system is required to adequately protect a component from corrosion. Application of solely a primer will not provide adequate corrosion resistance.

Before a coating is applied to a component surface, the surface should be dry and clean from contaminants and rust. For CUI applications, the surface prep will vary depending on the coating applied. The adequacy of the surface preparation can significantly impact the durability of the coating. Regardless, low levels of chlorides, ≤2 μg/cm^2 are recommended. For CUI applications, high-build epoxies or epoxy-phenolics are often specified at temperatures up to about 250 °F (121 °C). At higher temperatures, a high-temperature coating (e.g. a two-coat heat-resisting silicone coating) is required.

It should be noted that many coating systems fail after 10 years in service. After the coating breaks down, the bare steel can be attacked by CUI. By contrast, TSA coatings are generally reported to have a useful service lifetime in excess of 35 years though service life can be reduced because of improper coating application (see 11.5.4).

8.8.3 Caulking Considerations

Caulking should be done immediately after the insulation jacket is installed since moisture could enter through the open seams if left unsealed for a period of time. Protrusions or penetrations through the insulation, such as nozzles, support lugs, and so forth, should be sealed with a bead of good caulking compound. In order to achieve a satisfactory caulked joint, the separation between jacketing should not be greater than 3.2 mm ($^1/_8$ in.). A minimum of 6 mm ($^1/_4$ in.) of caulk should be applied to jacket joints. Caulking should not be featheredged since the life of the seal depends on uniform material thickness. Feathered edges curl and pull away from the jacketing.

Only silicone rubber caulking remains resilient for many years and is resistant to higher temperatures and many chemicals. Pigmented (i.e. colored) silicone rubber caulking provides a higher temperature and UV resistance compared to translucent-type caulk. With time, caulking materials dry out and lose flexibility. Areas around nozzles, manways, and on vessel heads should be inspected periodically to maintain the integrity of the insulation system.

For nonmetallic systems, only the caulking that is a certified part of the system shall be used and application shall comply with the manufacturer's installation procedures.

~~8.9 Shutdown/Mothballing~~ ME note: content nearly duplicated in 5.7. Captured a few points in 5.7

~~There is a high potential for CUI damage of insulated carbon and low alloy steel on equipment that will be shutdown or mothballed for an extended period. It is prudent to remove all insulation and fireproofing when equipment or piping systems are mothballed. Generally, corrosion rates of carbon and low alloy steels under insulation are significantly higher than atmospheric corrosion.~~

~~8.10~~8.9 Quality Control/Quality Assurance

The site should establish a quality control system covering the materials being used. The quality control system should include all steps from insulation procurement through the installation process. The quality control system should list the responsibilities of personnel inspecting the insulation materials and the responsibilities and training/certification requirements for personnel supervising the installation work. A quality plan should be developed that identifies and lists all hold and witness points. ~~It should also list all hold and witness points.~~ NACE SP0198 latest edition, Section 6, Inspection and Maintenance should be used as a reference for what to include in the visual inspection of an insulation system. In addition, PIP INTG1000, Insulation Inspection Checklist can be used as an example of items that should be reviewed throughout the insulation installation process.

Items that should be included in the quality plan are as follows:

- inspection of the insulation for proper storage during transport;
- plans for storage of the insulation prior to installation;
- remediation of any coating issues identified in the coating process or final coating inspection prior to applying the insulation;
- verification of the applied coating system against the required specifications prior to insulating;
- plans to protect partially installed insulation from the environment during installation;
- verification of the insulation materials to confirm that the correct materials are installed;
- verification of material thicknesses against the insulation specifications;
- verification of the installation requirements identified in the specifications, including ~~properly~~proper layering, method of securing insulation, jacketing type, and metal thickness.

9 Design Practices to Minimize CUF

9.1 General

9.1.1 Fireproofing is employed to minimize the escalation of a fire that would occur with the failure of structural supports and the overheating of pressure vessels. The failure point for steel is generally considered to be 1000 °F (537 °C). At this temperature, the yield strength of structural steel is roughly 50 % of its room temperature strength.

The goal of fireproofing is to prevent structural steel from reaching 1000 °F (537 °C) for some period of time to allow more time for plant personnel to:

- evacuate,
- fight the fire,
- shut off the fuel supply for the fire, and
- shut down the process to minimize the overall damage incurred.

9.1.2 The traditional method of fireproofing has been pour-in-place concrete or gunite. Other fireproofing materials, such as lightweight cements, prefabricated cementitious board, and intumescent coatings are used. Lightweight coatings are used primarily in areas where weight reduction is a significant benefit.

9.1.3 The decision to fireproof is driven by risk-based analysis. One needs to first consider the nature of the fire threat and then make an assessment of the required period of fire endurance for a wide variety of equipment including structural steel, pressure vessels, heat exchangers, pipe supports, liquefied petroleum gas spheres, and bullets, valves, and cable trays. The location of specific equipment within a process unit is important, as is a unit's location with regard to neighboring facilities. Guidance on the selection, application, and maintenance of fireproofing systems is provided in API 2218.

9.2 Dense and Lightweight Concrete

Structural steelwork and vessel skirts with concrete or vermiculite cement fireproofing should be coated with a two-coat system, prior to fireproofing, because of the effect of chlorides on the steel surface in moist environments. Weather shields should be installed, where feasible, at the top edge of the sealed, fireproofed joint to prevent water getting between the structural steel and the fireproofing. The use of nonpotable water and poor mixing can lead to reduced durability of concrete and cementitious fireproofing. Using water that contains high levels of chloride can lead to accelerated corrosion. Again, the buildup of corrosion products between the structural steel and the fireproofing can cause cracking and spalling of the fireproofing.

9.3 Lightweight Cementitious Products

As in the preceding section, the base metal substrate also needs to be coated with protective primers and topcoat sealers prior to fireproofing to diminish the risk for CUF. These materials are usually limited to areas that are not prone to mechanical damage and are typically used in areas above a 10 ft (3 m) elevation. Mechanical damage of these materials has been known to occur, thereby increasing the potential for CUF on the structure and reducing their overall effectiveness as fireproofing.

9.4 Intumescent Coatings and Subliming Compounds

Coatings that provide fireproofing by intumescing or subliming develop good adhesion to properly coated steel. As a result, the risk of CUF with these coatings is much reduced. It is important, however, that coating work conducted prior to the application of the fireproofing is done to a high standard. Additionally, the fireproofing manufacturer should be consulted to confirm that the surface primers are compatible with the intumescent coatings. It is important that the coatings are allowed to properly cure before the fireproofing is applied. Additionally, the fireproofing may require overcoating to protect it from long-term exposure to UV light. This exposure can be damaging to the fireproofing material. The fireproofing manufacturer should be consulted for their recommendations on overcoating.

9.5 Protective Coatings

There is always a chance that water may get behind fireproofing. In such a case, the coating is all that ~~is preventing~~prevents corrosion from occurring. It is therefore important that the proper coating be selected for the exposure conditions and that the surface be ~~prepared~~prepared, and the coating be applied in accordance with the manufacturer’s recommendation.

9.6 Quality Control/Quality Assurance

Fireproofing materials have evolved from traditional materials (i.e. dense and lightweight concrete) to higher technology materials (i.e. intumescent rigid/flexible epoxies, flexible endothermic wraps, etc.). Satisfactory performance of fireproofing depends on knowledge of materials and application techniques. Inspection by qualified personnel is also crucial in assuring that the fireproofing performs satisfactorily over the expected life of the fireproofing. It is essential that site and contract personnel are familiar with the site specification and fireproofing manufacturer’s requirements. API 2218 provides guidance on quality control of fireproofing.

10 Maintenance to Mitigate CUI/CUF Issues

10.1 General

Properly designed and installed insulation systems should normally require little maintenance. However, failing insulation systems are very often detected only when in poor shape and require significant repair. Routine maintenance practice should be extended to include~~by~~ periodic scheduled inspections and preventive maintenance on insulation ~~, and~~systems and can include a long-term strategy based on RBI principles.

Shortcomings can then be detected at the earliest stage, preventing uncontrolled deterioration of the insulation system with consequential risk of CUI/CUF. In particular, inspection surveys should be carried out after shutdowns because during shutdowns insulation systems are sometimes removed and not properly reinstalled or the systems are damaged (e.g. because of falling scaffolding poles).

After an inspection survey has been completed, the reported damage and remarks should be translated into a plan of action for remedial and preventive maintenance. The recommendations for preventive maintenance need to be prioritized for follow-up actions to prevent future or repeated damage to insulation or the underlying surfaces. Issues that should be considered are as follows.

a) Preventing water ingress due to inadequacy of design by:

1) repositioning of supports and brackets;

2) avoiding spraying firewater during fire drills on insulated tanks or equipment;

3) installing rainwater shields;

4) replacing damaged or saturated insulation; surfaces should be cleaned, derusted, and coated before installing the new insulating material.

5) Using insulation drying wraps

~~4)~~6)using non-contact insulation systems with low point drain holes

b) Preventing insulation/jacketing damage due to operations or maintenance activities by:

1) installing a walkway and/or platform over insulated pipes in a pipe track or at piping manifolds;

2) rerouting of pedestrians by putting up hand railings;

3) providing instructions to contractor/scaffolding personnel regarding appropriate protection of site insulation systems.

4) Provide instruction to other trades to not use insulated pipes/equipment as ladders, walkways, scaffold support.

~~3)~~5) Providing the reinforcement to the jacketing using designs/measures such as insulation drying wrap.

c) Removing unneeded insulation.

10.2 Programmed/Condition-based Maintenance

Based on the results of inspection surveys, the scope of long-term insulation maintenance can be determined, and priorities can be set in accordance with the reliability-centered maintenance principles.

In order to systematically control the upgrading of existing insulation in a plant, the various units should be divided into manageable areas indicated on a plot plan and the work carried out by area. Simultaneously, maintenance painting in the same area should be scheduled.

Deterioration of caulked joints is a likely spot for water ingress into insulation systems. Consideration should be given on a prioritized basis to a preventative maintenance program for recaulking higher risk piping and equipment (e.g. class 1 systems) on a scheduled basis.

Progress of work can then be properly recorded, and costs for scaffolding should decrease substantially as compared to when piping systems are followed or when work is carried out randomly throughout the plant. It should be noted that risk mitigation needs to be balanced with effective cost management. Site personnel should determine the effectiveness of block rejuvenation by recognizing that some higher risk equipment/piping will not be mitigated until the block maintenance crew arrives at a later date.

10.3 Execution

When executing maintenance work, care should be taken to remove existing insulation materials in order to allow their reuse. Slabs, pipe sections, or preformed covers for valves, fittings, etc. should be removed carefully and properly stored.

Temporary protection should be provided to adjacent insulation to prevent damage or water ingress during mechanical maintenance work.

After repair of damaged hot insulation, the jacketing of the replaced area and its direct vicinity should be checked to establish proper repair of the weather protection of the complete system. For cold insulation, the vapor retarder ~~barrier~~ of the replaced area should be applied with sufficient overlap on the existing undamaged vapor retarder ~~barrier~~.

10.4 Deluge System Issues

All of the normal inspection issues associated with CUI/CUF will also apply in areas under deluge systems. Communications with safety and operations to avoid spraying equipment and piping during testing of deluge systems will help prevent many CUI/CUF issues. Periodic inspection using either neutron ~~back~~ backscatter or IR thermography should be considered because of the high potential for finding wet insulation in these systems. Periodic maintenance of the weather shield is an important step in preventing CUI damage of equipment under deluge systems and should include:

- repair of damage to the weather shield;
- inspection and removal of drain hole blockages;
- resealing of any damaged weather shield seams;
- repair of damaged coatings when detected;
- routine external visual inspections of the integrity of the insulation system.

10.5 Mitigation of CUI/CUF Damage

10.5.1 General

There are several approaches that are used to mitigate CUI/CUF damage. These include approaches to protecting the surface of the metallic piping (i.e. organic coatings, TSA, and aluminum foil for stainless steel), the installation of protective cages in locations where piping is insulated solely for personnel protection and performing periodic maintenance on the insulation system.

10.5.2 Organic Coatings

The application of organic coatings on carbon steel equipment beneath insulation is an effective method of having a physical barrier to the corrosive electrolytes. Organic coatings are effective only if the surface has been prepared properly and a holiday-free coated surface is obtained. In general, the average life of an organic coating system is 5 to 13 years. In some cases, when a correctly selected and applied coating system is used, a 20-year service life can be achieved. Some of the parameters that need to be considered when selecting a coating system include:

- surface-preparation requirements;
- environmental requirements;
- compatibility with insulating material;
- coating tests;
- coating vendor selection;
- specifications;
- inspection;
- selection of a coating applicator.

Coating systems that have been used successfully in the process industries include liquid-applied coatings such as epoxies, fusion-bonded coatings, mineralization coatings, and tapes. More information on the selection of protective coatings is available from coating manufacturers' literature and in NACE SP0198.

10.5.3 Aluminum Foil to Protect Austenitic/Duplex Stainless Steel

Experience has shown that organic coatings do not necessarily provide an effective barrier to ECSCC. When properly installed, aluminum foil wrapping of piping is an effective method to protect austenitic and duplex stainless steel from ECSCC. The primary benefit of aluminum foil wrapping is by acting as a sacrificial anode to provide electrochemical (i.e. cathodic) protection against ECSCC. The wrapped aluminum foil may also act as a barrier, but its ability to serve as a barrier is highly dependent on its application.

Prior to wrapping, the surface should be washed with demineralized water to remove chloride from the uncoated piping. Solvent cleaning (i.e. SSPC SP-1) is not necessary unless oil or grease is present on the surface. Aluminum foil wrapping of the piping takes less time to install than applying a coating to the surface of the pipe. As shown in Figure ~~27~~36, vertical sections of piping should be wrapped from the lowest point of the run to the highest point of the run to prevent water from getting under the aluminum foil. Aluminum or stainless wire should be used to hold the foil in place. Foil should be molded around flanges and fittings. Steam-traced lines should be double wrapped, with the first layer applied directly to the pipe, followed by the steam tracing, and then the second layer of foil over the top of the steam tracing.

Although aluminum foil has been effective in preventing ECSCC under thermal insulation on austenitic and duplex stainless steel piping and vessels, its use may be limited to application on piping of 24 NPS or smaller based on economics. Above 24 NPS, piping and vessels use of TSA is generally more economic. Successful long-term use of aluminum foil relies on the maintenance of the weatherproofing system. While the aluminum foil does provide protection from ECSCC in immersion conditions, its life is greatly reduced.

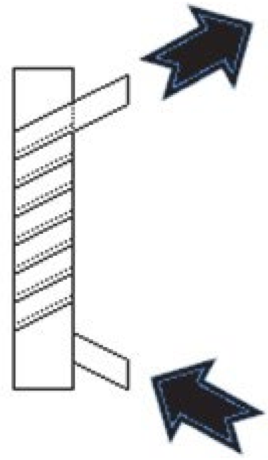


Figure ~~27~~36—Vertical Piping Should Be Wrapped from Bottom-to-Top with an Overlap

10.5.4 Thermal Spray Aluminum to Protect Steel

Thermally sprayed aluminum coatings are applied by either the electric arc spraying (also referred to as metallizing) or oxy-fuel wire spraying (also referred to as flame spraying) process (see Figure ~~28~~ 37 and Figure ~~29~~38).

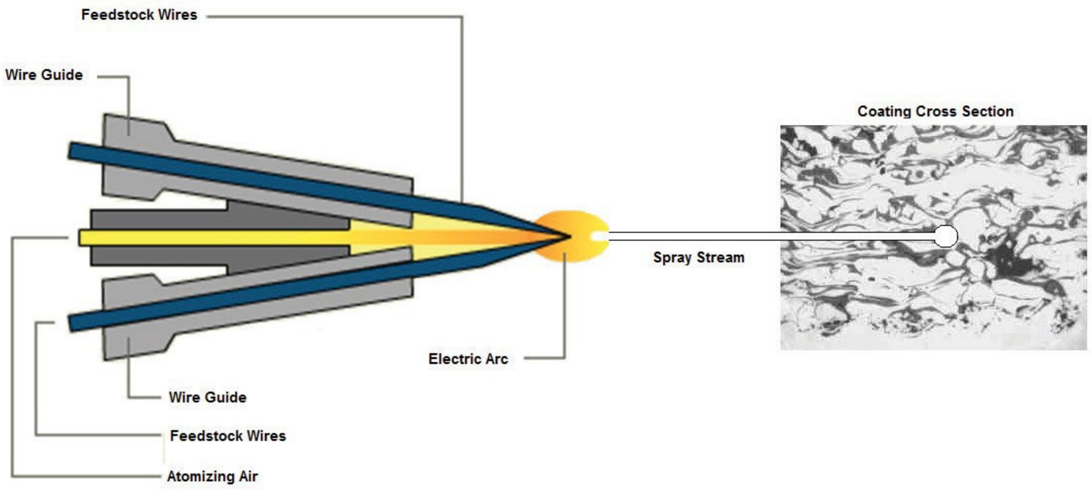


Figure ~~28~~37—Schematic of Two-wire Electric Spray Processes and Deposit Microstructure

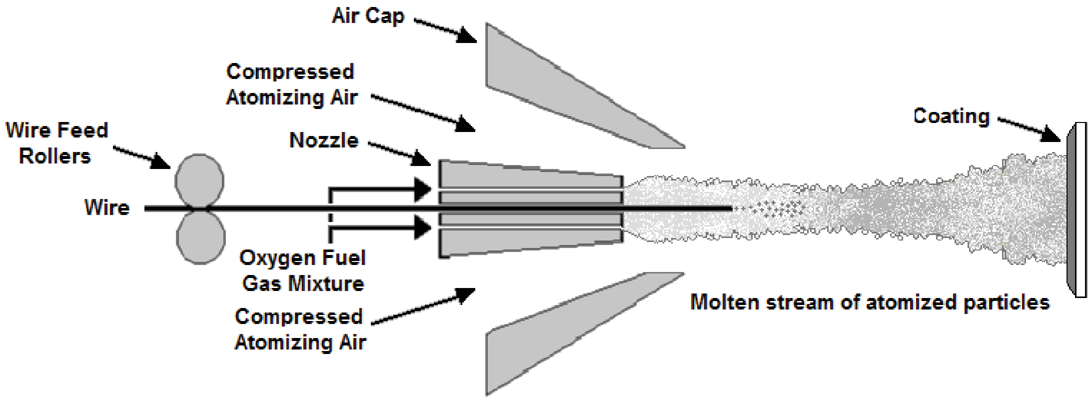


Figure ~~29~~38—Schematic of Oxy-fuel Wire Spray Processes

In the electric spray process (see Figure ~~28~~37), the two aluminum wires are continuously fed toward each other to the gun tip at a uniform speed. A low-voltage direct current power supply is used, with one wire serving as the cathode and the other as the anode. As the wires leave the wire guides, they produce an electric arc at the point just before the wires meet. The high-temperature arc [>9000 °F (>5000 °C)] that is produced melts the wires. High-pressure compressed air, injected into the gun, produces a fine spray of aluminum droplets. As the spherical droplets impact the surface, they flatten to produce a platelet-like structure that is a mixture of coating, oxides, and porosity. A high magnification view of the deposit cross section is shown in Figure ~~28~~37. The particles are mechanically bonded to the metal substrate.

In the oxy-fuel wire spray process (see Figure ~~29~~38), drive rollers continuously feed the wire to the tip of the spray gun. A mixture of a combustion gas (i.e. either acetylene, propane, or methyl acetylene-propadiene) and oxygen are combined and ignited at the tip of the spray gun to melt the wire. The molten metal is then atomized by the surrounding jet of compressed air, creating a stream of aluminum droplets that are propelled to the metal substrate. The flame temperature of the combusted gas is significantly lower than the arc temperature of two-wire electric process [i.e. ~3100 °F (~1700 °C)]. Flame spray deposits are primarily mechanically bonded to the metal substrate and have lower bond strength than the two-wire electric spray process.

Since weather barriers and insulation are often not well maintained at regular intervals, a good, well-adhered surface coating is an important parameter in preventing CUI damage to the equipment and piping. Another key factor to a long service life for the coating is a well-prepared surface. At a minimum, the surface needs to be prepared to a near-white-metal blast cleaned surface (SSPC SP-10 or equivalent).

Aluminum's affinity for oxygen and adherent and non-water-soluble oxide provides long-term CUI protection by serving as a barrier film and then providing catholic protection to the underlying carbon steel at breaks in the coating. TSA applications emit no volatile organic compounds and do not require "dry time" between coats. Two key elements to minimize the potential for CUI include having a surface that has been abrasively blasted to a near-white-metal condition (i.e. SSPC SP-10 or greater) and a coating thickness of 0.010 in. (0.25 mm). The minimum thickness of 10 mils, applied in one application by a crosshatched spray pattern, deposits a near pore free barrier surface with minimum size that will fill with aluminum oxide in service.

The importance of applied thickness in determining service life of the TSA is illustrated in Equation (1), developed by Thomason [20].

$$\mathrm{SL} = \frac{0.64 \times t_{\mathrm{TSA}}}{A_{\mathrm{s}}} \tag{1}$$

where

SL is the service life (years);

t_{TSA} is the thickness (μm);

A_{s} is the percentage of area of bare steel.

The service life approximation based on Equation (1) does not take into account the barrier effect of the TSA coating. It only takes into account that the failure mode of TSA is from anodic dissolution of the aluminum as it supplies cathodic protection to the carbon steel.

TSA coatings are generally reported to have a useful service lifetime in excess of 35 years. Within the past few years, there have been a few reports of TSA coatings failure in onshore and offshore applications after less than 10 years of service. Factors that can influence the performance of TSA coatings include the following.

a) Quality of Surface Preparation—The steel surface should be prepared to an SSPC SP-10 or SIS Sa 2 $^{1}/_{2}$ surface finish.

b) Quality of the Wire—The wire should be free of kinks and should not contain visible oxide particles on the surface of the wire that could affect application, density, or adhesion of the coating.

c) Environmental Conditions—The relative humidity should be less than 85 %, and the steel surface temperature should be at least 5 °F (3 °C) above the dew point throughout the blasting and coating process.

d) Coating Thickness—The as-applied TSA thickness should not be less than 0.010 in. (250 μm) thick.

e) Sealer Application—When overcoated with an organic coating, the seal coat should not be greater than 0.002 in. (50 μm) thick.

f) Applicator/Operator Experience—When an applicator/operator has limited experience, the ~~owner/user~~owner-operator should consider increased QA/QC controls.

Additional information may be found in NACE No. 12/AWS C2.23M/SSPC-CS 23.

10.5.5 ~~Tape~~ Protective~~ ~~Wraps

~~Petroleum-based tape~~ Various wrap~~ped~~ systems have been developed to protect metal surfaces in severe environments and for difficult to protect geometries~~. (see Figure 30)~~. Generally, there are bonded and unbonded wrap systems.

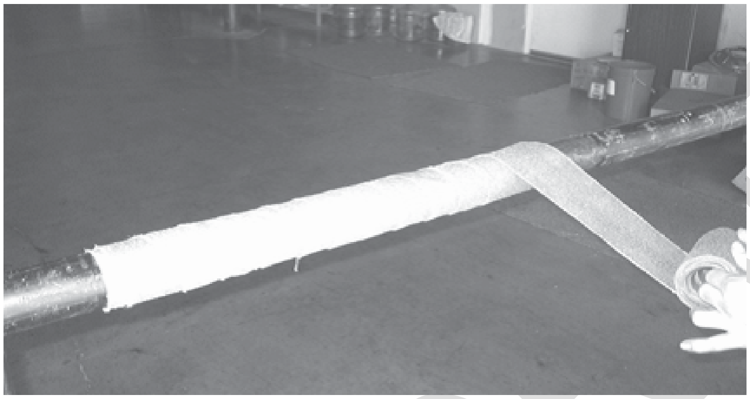
A common bonded system is petroleum-based tape ~~These systems are~~ typically composed of:

— a surface priming paste to displace surface moisture, passivate surface oxides, and fill in small irregularities in the substrate;

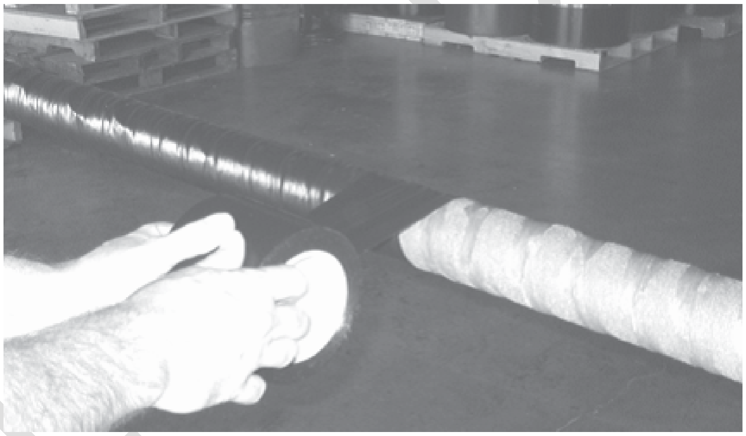
— a mastic filler to ease contours around irregular shapes such as pipe joints, flanges, valves, bolts, and other irregular shapes; and

- a nonwoven bonded synthetic fabric, fully imbedded ~~impregnated~~, and coated with natural petroleum (see Figure 39).

Tape systems require frequent maintenance to maintain the seal and prevent water ingress. The tape wrap can deteriorate or open up over time, developing crevices that result in accelerated external corrosion rates, often higher than those experienced for insulated systems.



a) Nonwoven Bonded Synthetic Fabric Imbedded~~pregnated~~ with Natural Petroleum Being Applied to a Mastic Coated Surface



b) PVC Film Being Applied Over a Petroleum-based Tape Wrap

Figure ~~30~~39—Example of a Petroleum-based Tape Wrap System

Prior to application of the priming paste, the surface should be solvent cleaned (per SSPC SP-1) to remove dirt, grease, and oil from the surface. In addition, weld spatter and sharp points/edges should also be removed. Hand or power tools (per SSPC SP-2/SSPC SP-3 or SSI St. 2/SSI St. 3) can be used to remove loose surface rust, paint, and foreign matter from the surface. High-pressure water blasting may be used to prepare the surface.

In some situations, a stabilized, plasticized, PVC film coated with an anticorrosive pressure-sensitive adhesive can be used to wrap over petrolatum tapes to provide color coding and additional protection [see Figure ~~30~~ 39 b)]. These systems wraps have been used in some offshore applications to replace metallic jacketed insulation because of their ability to provide an improved sealing capability.

An example of an unbonded system is a dimpled PTFE wrap (see Figure 40). The wrap gives impermeability against dripping moisture and leachate to help prevent CUI risks. Dimpled stand-off wraps provide an air gap that allows drainage of moisture and prevents concentration cell corrosion, a CUI mechanism. Unbonded wraps do not have any surface preparation requirements. For application on complex geometries (e.g. pipe shoes, bends, sweeps), these geometries can be prefabricated to match.

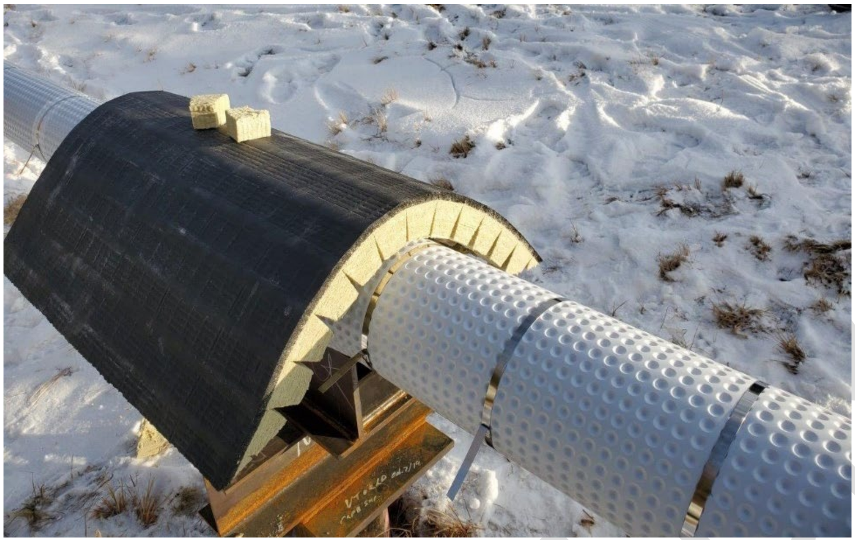


Figure 40 Dimpled PTFE Wrap (non-adhesive type)

Another type of unbonded wrap is an insulation drying one (see Figure 41). Perforated and dimpled insulation drying wraps dry out moisture-soaked insulations by being breathable. Accelerated drying allows insulations to regain their thermal properties. In addition, the dimpled stand-off imparts compressive strength to the jacketing that otherwise can get crushed and deformed from external loading and foot-traffic.

Figure 41 - Perforated and dimpled Insulation drying wrap system

10.5.6 Personnel Protective Cages

Equipment or piping operating above 140 °F (60 °C) poses a risk to personnel when skin comes in contact with the hot metal surface. In many instances, these surfaces are insulated for the sole purpose of personnel protection from the hot metal surface. The unnecessary use of thermal insulation creates a location for potential corrosion. In these cases, the insulation should be ~~removed~~removed, and wire "standoff" cages should be used instead. These cages are simple in design, low in cost, and eliminate CUI concerns and costs associated with maintenance of the insulation system. Care should be taken to design standoff cage mounting systems to eliminate contact point corrosion. Examples of different types of personnel protective cages are shown in Figure ~~31~~42.

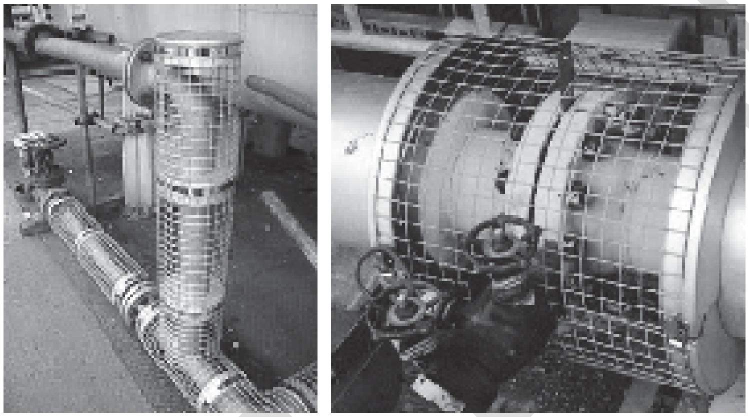


Figure ~~31~~42—Photograph of a Personnel Protective Cage on a Vertical and Elbow Section of Piping (left) and a Removable Personnel Protective Cage on a Valve (right)

10.5.7 Insulation System Maintenance

10.5.7.1 General

Regardless of the type of jacketing and insulation, jacketing is used to assist both the short-term and long-term performance of the insulation in the particular application. Assuming the insulation system has been properly designed and installed correctly, it will only perform as designed if properly maintained.

10.5.7.2 Jacketing

Breaches in the jacketing system, as shown in Figure 2 and Figure ~~32~~43, serve as potential access points for water ingress. The areas directly below these jacketing breaches are prone to CUI damage. Damage is likely to occur at the low point of the piping run where water can accumulate. The solution to this problem is to make sure the insulation is properly supported, replace damaged insulation, and reinstall the insulation jacketing.

10.5.7.3 Caulking and Sealants

Figure ~~32~~43 shows one of the piping segments (i.e. left arrow) with newly jacketed insulation system. The lap and butt joints of the jacketing are effectively sealed with caulk piping to prevent moisture ingress. However, when temperatures change, materials expand and contract causing cracks in the caulking, allowing moisture to penetrate the insulation system. Damage to the caulk seal may not be detected until the jacketing is removed. If undetected, CUI of the piping can occur. The only effective solution for this issue is to periodically dismantle a section, inspect the sealants, and determine whether the entire system needs to be resealed.

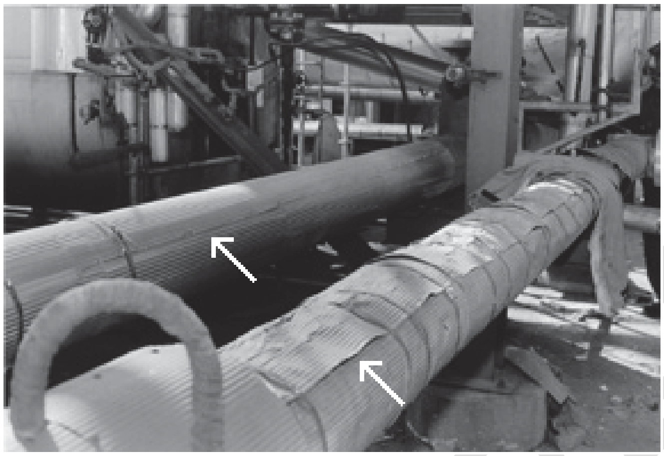


Figure ~~32~~43—Photo Showing Piping with and without Damage to the Insulation System

10.5.7.4 Insulation

Figure ~~32~~ 43 also shows one of the piping segments (i.e. on right) with significant damage to the insulation system, both the insulation and jacketing, due to excessive foot traffic. Failure to replace this insulation system may result in excessively high heat loss and water intrusion. This has the potential to cause CUI damage to the piping. One solution to this problem would be to replace the entire insulation system and to install a stairway to prevent unsafe foot traffic.

10.5.8 Installation Craftsmanship

10.5.8.1 General

Installation craftsmanship of jacketing/weather barriers can have a great effect on an insulation system's performance and life. It is a critical problem with those insulation systems that operate in the CUI temperature range, cycle in temperatures, or may be shut down for periods of time. A poorly installed insulation system ultimately lets moisture or corrosive chemicals into the insulation, and often to the insulated surface, allowing the start of CUI.

10.5.8.2 Caulking and Sealants

Caulking and sealants are barriers to moisture intrusion and may be installed improperly in a number of ways. They may not be installed (see Figure ~~33~~44) or may be installed incorrectly either by missing sections or by wiping or smoothing the sealant bead once it has been installed.

Smoothing the sealant is often done to provide a more attractive finished appearance but may result in a large amount of the sealant material being removed. This can potentially reduce the life of the sealant and increase the chance of a leak.

Figure ~~33~~44—Example of Jacketing Joint with Missing Caulking

10.5.8.3 Jacketing

Jacket materials installed with improper “fit and finish” provide easy path for water access (see Figure ~~34~~45). Gaps between jacket components larger than 0.125 in. (3.2 mm) cannot be successfully sealed with caulking and sealants. Stresses and natural movement between these parts can cause the sealants to fail prematurely, letting in moisture and contaminating the insulation.

Figure ~~34~~45—Example of Poor Jacketing Fit-up

Jacketing or weather barriers can also be installed improperly by not providing the proper ability to shed rain (see Figure ~~35~~46). On vertical sections, this happens when lower sections of the jacketing material are installed over the top of the upper sections. On horizontal sections, it happens when the lap section is installed close to the top or bottom of piping rather than to the sides. It can also happen when a section of jacketing is wrapped around the insulation such that the upper section of the jacket horizontal lap is overlapped by the lower section. All of these installation errors allow water into the insulation system.

Insulation terminations (i.e. end caps) are places where jacketing can be installed improperly. Sometimes they can be omitted entirely with obvious CUI risks. In addition, end caps installed on vertical lines that are improperly sealed or without attention to shedding rainwater can lead to CUI problems (see Figure ~~36~~47).

The final craftsmanship issue relates to storage and handling of insulation materials prior to installation. Insulation materials need to be stored in a dry location and need to be protected from exposure to rain and weather prior to installation of the jacketing. Insulation materials stored on the ground without any water-resistant covering can lead to insulation being installed wet.

Figure ~~35~~46—Examples of Joints with Poor Ability to Shed Water

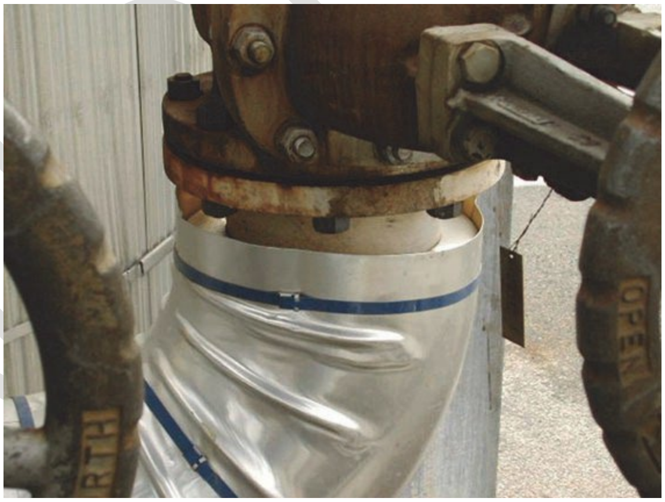


Figure ~~36~~47—Example of Missing End Cap

10.6 Mitigation of CUF Damage

Corrosion on structural members protected by fireproofing causes multiple problems. Initially, the trapping of water behind the fireproofing causes corrosion of the structural member. The steel corrosion products occupy a much greater volume than the un-corroded steel. This leads to cracks forming in the fireproofing that allow greater water ingress. In colder environments this can be exacerbated by the expansion that occurs as the water freezes.

There are several factors that promote CUF damage on vessel skirts and structural steel supports. Poor design of the fireproofing system can result in trapping water between the fireproofing and the underlying steel. Also, inadequate sealing of the fireproofing-to-steel termination joint may also allow water to be trapped behind the fireproofing. The lack of protective coatings on fireproofed substrates can contribute to rapid corrosion. Approaches to these issues include:

- installation of weather shields to direct water away from fireproofing terminations;

- coating fireproofed substrates for corrosion protection.

In addition to the above, it should be noted that when intumescent or subliming fireproofing compounds are used, the fireproofing manufacturer needs to provide a list of compatible coatings for use with their material. Also, inorganic zinc coatings used on their own are not effective coatings under fireproofing. Zinc is amphoteric and can be attacked in the alkaline conditions that exist beneath concrete and cementitious fireproofing.

11 Repair Techniques/Strategies

11.1 General

The repair of CUI on equipment and piping depends on the degree (i.e. severity) of damage ~~of~~to the component. When CUI is within the original corrosion allowance for the component, the repair strategy might be as simple as cleaning the corroded surface and recoating the affected area. When CUI damage is beyond the original corrosion allowance for the component, the repair strategy could be complex involving fitness-for-service (FFS) analysis along with section replacement or extensive weld buildup.

When developing an appropriate repair strategy, site personnel need to establish whether the repair will be temporary or permanent. As indicated API 510 and API 570, temporary repairs should be removed and replaced with a suitable permanent repair at the next available maintenance opportunity. Temporary repairs may remain in place for a longer period of time only if approved and documented as required by the appropriate API in-service inspection code.

ASME PCC-2 is the primary source for information on repairs. The following section discusses CUI concerns only.

11.2 Surface Coatings

The use of surface coatings may be considered when CUI damage does not exceed the original corrosion allowance of the component. Any surface coating that is considered should be resistant to hot water immersion since the environment under insulation is very aggressive toward coatings. A key parameter in maximizing the life of a surface coating is the quality of the surface preparation and the cleanliness of the surface. NACE SP0198 lists typical coating systems used for carbon steel and austenitic/duplex stainless steel equipment and piping, along with:

- temperature range for each coating system;

- level of surface preparation requirements;

- surface profile requirements;

- recommended thickness range for prime, and topcoat.

11.3 Weld Repairs

When the wall loss of the component exceeds the original corrosion allowance, an FFS analysis should be considered. When an FFS analysis indicates that continued operation is not an acceptable option, the equipment or piping system should be removed from service in order to affect a repair. A typical repair strategy for a locally corroded area would be to restore the wall thickness by weld buildup of the damaged area. As with any weld repair, the damaged area needs to be cleaned and prepared for welding. Typically, these repairs are made while the equipment or piping system is not in service. An in-service repair is possible provided that necessary proper precautions for in-service welding are taken. An evaluation of the type of insulation adjacent to the welding area should be conducted to determine if it is flammable or has absorbed a flammable substance. It may be necessary to conduct a risk assessment as part of the development of the repair strategy.

~~Reader should reference~~ Refer to ASME PCC-2 Part 2 for additional information.

11.4 Safety Issues

11.4.1 General

Safety precautions are important during maintenance or inspection activities because some process fluids are harmful to human health. Any maintenance, inspection, or repair work on in-service equipment poses hazards that need to be risk assessed prior to initiation of the activity. When conducting these activities, personnel should review the site safety procedures prior to the initiation of work. A leak or failure in a piping system may be only a minor inconvenience, or it may become a potential source of fire or explosion, depending on the temperature, pressure, contents, and location of the piping. Piping in a petrochemical plant may carry flammable fluids, acids, alkalis, and other harmful chemicals that would make leaks dangerous to personnel.

11.4.2 Maintenance/Cleaning Hazards

11.4.2.1 General

There are potential risks associated with the removal of the jacketing and insulation. The removal of the insulation from in-service piping potentially exposes hot metal surfaces. If personnel contact the hot (or cold) surface, they may be exposed to injury (i.e. burns). Removal of surface scale on piping can also lead to a process leak if the CUI damage is significant. This would expose personnel to the leakage of hot fluids.

In addition to these hazards, there are other concerns related to how scale is removed from the surface of the component. Cleaning personnel need to be careful to avoid coming in contact with blasting grit or debris from the cleaning process. Personnel performing hydroblasting should avoid contact with high-pressure water when removing external corrosion scale.

11.4.2.2 Asbestos and Lead Coating Removal

Surfaces coated with lead-based coatings or insulated with asbestos also require special precautions and experienced contractors when being removed from surfaces with CUI damage. Before any work with asbestos or lead coating is carried out, OSHA regulations (29 *CFR* Part 1910.1001) require employers to make an assessment of the likely exposure of employees to asbestos and lead dust, including providing a description of the precautions that need to be taken to control dust to protect workers and others from exposure.

11.4.3 Inspection Hazards

11.4.3.1 General

In order to assess the condition of the piping, it is often necessary for personnel to be able to see the clean pipe surface. This necessitates removal of the scale from the pipe surface. Often this is done using either a file or a flapper wheel. There have been instances where minimal removal of surface scale has caused a hole in the piping. When equipment is in operation, it is necessary to evaluate the risks associated with preparing the surface prior to inspection. Removing scale on thinned piping can expose inspection personnel to hot process fluid. Often, inspection personnel will inspect piping for thinned areas by tapping a hammer on the surface of the piping. Thinned areas will sound different than areas that are thicker. Here too, areas that are corroded may develop a hole from hammering if they are severely thinned, exposing inspection personnel to hot process fluid. This should not be done on operating equipment.

When equipment is in operation, it is necessary to evaluate the risks associated with preparing the surface prior inspection. Removing scale on thinned piping can expose inspection personnel to hot process fluid.

11.4.3.2 Work on Operating Equipment

Intrusive work on operating equipment should be performed only after careful review. Often it is very difficult to assess the condition of insulated equipment for CUI damage. It may be necessary to use several inspection techniques to minimize exposures. When it is necessary to remove corrosion product, some things to consider include the thickness of the scale, remaining corrosion allowance, and inspection effectiveness. Activities such as sandblasting and scraping areas with heavy scale should be avoided on live equipment. When that is impractical, a job hazards review should be considered. An epoxy coating of equipment with a scale sealing paint may be desired until a shutdown window can be met.

Annex A
(informative)

Examples of ~~a Qualitative~~ Likelihood Assessment Systems

A.1 General

There are a variety of approaches and methodologies that can be employed in conducting likelihood assessments. Shown below are two examples, one is a simplified qualitative points-based approach, and the other is a simplified semi-quantitative score-based approach.

A.2 Qualitative Likelihood Assessment Systems

A.2.1 General

Shown below is a simplistic approach to demonstrate how a points-based approach might be employed and is presented only as an example (Table A.1). When utilizing a points-based approach, the relative weighting of each factor, or additional factors impacting CUI or CUF damage at a site, should be based on site experience.

In this case, the parameters least likely to promote CUI are assigned the lowest points. The corresponding likelihood ratings for carbon and low alloy steels are given in Table A.2. The lowest likelihood is associated with the fewest overall points.

A.2.~~1~~2 CUI Assessment for Carbon and Low Alloy Steels

Table A.1—Example of Points-based Parameter Rating for Likelihood of CUI

Parameter	0	1	3	5
Operating temperature		25 °F to 100 °F or 270 °F to 350 °F (–4 °C to 38 °C or 132 °C to 177°C)	100 °F to 170 °F or 230 °F to 270 °F (38 °F to 77 °F or 110 °C to 132 °C)	170 °F to 230 °F or cyclic service from >350 °F to <230 °F (77 °C to 110 °C or cyclic service from >177 °C to <110 °C)
Coating/age	Quality coating within 8 years or system age <15 years	Quality coating within 15 years or system age <30 years	General coating 8 to 15 years	General coating age >15 years, system age >30 years, or unknown
Jacketing/ insulation condition	System age <5 years without deficiencies	Average condition with good maintenance (such as sealed, no gaps, CML ports with plugs)	Average condition with some deficiencies	Damaged condition with several deficiencies
Heat tracing	None	High-integrity steam system or electric tracing	Steam system with medium integrity	Steam system with visible leaks
External environment	No sweating	Arid and inland	All other locations	Coastal/marine, cooling tower overspray, or local external water source exposure (deluge systems, dripping steam condensate)
Insulation type	No insulation, cellular glass,	Expanded perlite [2*], ~~cellular glass,~~	Type E Fiberglass [2*], Fiberglass,	~~Traditional m~~Mineral wool, asbestos, unknown/unspecified

	insulating coatings	~~corrosion inhibiting calcium silicate,~~ microporous blanket insulation	~~silica~~flexible aerogel [2*], ~~water-resistant~~ mineral wool (water-resistant), Calcium Silicate [2*]	
Line size or nozzle size	Equipment	>6 in.	>2 in. to 6 in.	≤2 in.

NOTE System age is defined as the time since last insulation/jacketing installation or replacement.

NOTE 2* Use "0" for any insulation complying with Mass Loss Corrosion Rate (MLCR) less than deionized (DI) water values calculated as per ASTM C117

Table A.2—Likelihood Rating

Parameter rating total	<7	7 to <14	14 to 20	>20 to 27	>27
Likelihood rating	A (Lowest likelihood)	B	C	D	E (Highest likelihood)

A.2.~~2~~3~~3~~ CUI Assessment for Austenitic and Duplex Stainless Steels

A similar example for austenitic and duplex stainless steels is given in Table A.3. Again, the lowest likelihood is associated with the fewest overall points, as shown in Table A.4.

Table A.3—Example of Points-based Parameter Rating for Likelihood of CUI

Parameter	0	1	3	5
Operating temperature		120 °F to 140 °F (49 °C to 60 °C)	250 °F to 400 °F (121 °C to 204 °C)	140 °F to 250 °F (60 °C to 121 °C)
Coating/age	Quality coating within 8 years	Quality coating within 15 years	General coating 8 to 15 years	General coating >15 years or unknown
Jacketing/ insulation condition	No deficiencies	Average condition with good maintenance (such as sealed, no gaps, CML ports with plugs)	Average condition with some deficiencies	Damaged condition with several deficiencies
Heat tracing	None	High-integrity steam system or electric tracing (Cl-free covering)	Steam system with medium integrity	Steam system with visible leaks or electrical with PVC covering
External environment	No sweating	Arid and inland	All other locations	Coastal and marine, cooling tower overspray, or external water source exposure (deluge systems, dripping steam condensate)
Insulation type	No insulation, insulating coatings	Expanded perlite, cellular glass, corrosion inhibiting calcium silicate, microporous blanket insulation	Fiberglass, silica aerogel, water-resistant mineral wool	Traditional mineral wool
Line size or nozzle size	Equipment	>6 in.	>2 in. to 6 in.	≤2 in.

NOTE Duplex stainless steels are more resistant to ECSCC, and it may be warranted to increase parameter rating.

Table A.4—Likelihood Rating

Parameter rating total	<7	7 to <14	14 to 17	>20 to 27	>27
Likelihood rating	A (Lowest likelihood)	B	C	D	E (Highest likelihood)

A.2.~~3~~4~~4~~ CUF Assessment

A similar example for CUF is given in Table A.5. Again, the lowest likelihood is associated with the fewest overall points, as shown in Table A.6.

Table A.5—Example of Points-based Parameter Rating for Likelihood of CUF

Parameter	0	1	3	5
Operating temperature		120 °F to 140 °F (49 °C to 60 °C)	250 °F to 400 °F (121 °C to 204 °C)	140 °F to 250 °F (60 °C to 121 °C)
Coating/age	Quality coating within 8 years or system age <15 years	Quality coating within 15 years or system age <30 years	General coating 8 to 15 years	General coating >15 years, system age >30 years, or unknown
Fireproofing condition	System age <5 years without deficiencies	Average condition with good maintenance	Average condition with cracking evident	Damaged condition
Potential for water ingress	None	—	—	Design allows for water ingress/travel from above
External environment	No sweating	Arid and inland	All other locations	Coastal and marine, cooling tower overspray, or external water source exposure (deluge systems, dripping steam condensate)
Material type	Intumescent coating, silica aerogel flexible blanket, high-temperature, water-resistant stone wool	Cementitious	—	Calcium silicate, mineral fiber insulation
NOTE System age is defined as the time since last insulation/jacketing installation or replacement.				

Table A.6—Likelihood Rating

Parameter rating total	<7	7 to <12	12 to 16	>16 to 19	>19
Likelihood rating	A	B	C	D	E

A.3~~.1~~ Semi-Qualitative Likelihood Assessment Example

A.3.1 General

Shown below is a simplified semi-qualitative approach to demonstrate how a score-based approach, aligned with the API RP 581 likelihood methodology, might be employed, and is presented only as an example. When utilizing this approach, the relative weighting of each factor, or additional factors impacting CUI damage at a site, should be based on site experience.

A.3.2 CUI Assessment for Carbon and Low Alloy Steels

For carbon and low alloys steels, a base CUI corrosion rate is determined from the combination of operating temperature and external environment in Table A.7. For assigning the external environment, the following descriptions are offered:

a) Severe—High wetting; very high rainfall; frequent deluge testing; highly corrosive industrial atmosphere; in a coastal zone with very high atmospheric chloride content.
b) Moderate—Frequently wet; downwind of a cooling tower; high rainfall; corrosive industrial atmosphere; near the coast with high chloride content in rainwater.
c) Mild—Occasionally wet; moderate rainfall; low chloride content in rainwater.
d) Dry—Very dry or cold zone with very low pollution and time of wetness; low rainfall; inside building (operating above dew point); low chloride content in rainwater.

The base CUI corrosion rate is then multiplied by each of the insulation factors (insulation type, insulation complexity, and insulation condition) in Table A.8 to determine a final CUI corrosion rate. A likelihood factor, based on component age, coating life in Table A.9, and component thickness, is calculated as follows:

Likelihood Class Factor = (component age – coating life) * final CUI corrosion rate / component thickness

Note that the component age is based on the original in-service date and the component thickness is obtained from original documentation such as Piping Line Lists and Equipment drawings.

The corresponding likelihood ratings for carbon and low allow steels are given in Table A.10. The lowest likelihood is associated with the lowest likelihood factor score.

~~CUI Assessment for Carbon and Low Alloy Steels~~

Table A.7 - CUI Base Corrosion Rate

External Environment	**Dry**	**Mild**	**Moderate**	**Severe**
Operating Temperature	**CUI Corrosion Rate mpy (mm/yr)**			
< 10 °F (< -12 °C)	0 (0)	0 (0)	0 (0)	0 (0)
< 18 °F (< -8 °C)	0 (0)	0 (0)	1 (0.025)	3 (0.076)
< 43 °F (< 6 °C)	1 (0.025)	3 (0.076)	5 (0.127)	10 (0.254)
< 90°F (< 32 °C)	1 (0.025)	3 (0.076)	5 (0.127)	10 (0.254)
< 160 °F (< 71 °C)	2 (0.051)	5 (0.127)	10 (0.254)	20 (0.508)

< 225 °F (< 107 °C)	1 (0.025)	1 (0.025)	5 (0.127)	10 (0.254)
< 275 °F (< 135 °C)	0 (0)	1 (0.025)	2 (0.051)	10 (0.254)
< 325 °F (< 162 °C)	0 (0)	0 (0)	1 (0.025)	5 (0.127)
> 350 °F (> 176 °C)	0 (0)	0 (0)	0 (0)	0 (0)

Table A.8 Insulation Adjustment Factors

Insulation Type	Expanded perlite, cellular glass, corrosion inhibiting calcium silicate, microporous blanket insulation	Fiberglass, silica aerogel, water resistant mineral wool	Traditional mineral wool
	0.75	1	1.25
Insulation Complexity	Minimal penetrations and branches	Some penetrations and branches	Many penetrations and branches
	0.75	1	1.25
Insulation Condition	No sign of damage or standing water	Average condition with some deficiencies	Damaged condition with some deficiencies.
	0.75	1	1.25

Table A.9 - Coating Life (yrs)

Coating Life (years)	None or Unknown	General Coating	Quality Coating
	0	8	15

Table A.10 – Likelihood Ratings

Likelihood Class Factor	Likelihood Class Number	Likelihood Class Descriptor
<= 0.10	1	Highly Unlikely
<= 0.14	2	Unlikely
<= 0.18	3	Possible
<= 0.60	4	Quite Likely
> 0.60	5	Likely

A.3.3 CUI Assessment for Austenitic Stainless Steels

Similarly, for austenitic stainless steels, a base ECSCC susceptibility is determined from the combination of operating temperature and the external environment in Table A.11. The base ECSCC susceptibility is then adjusted by adding the insulation factors (insulation complexity, condition, and chloride content) in Table A.12 to determine a final susceptibility score. An ECSCC Severity Index (SVI) is assigned based on the final susceptibility score and Table A.13.

A likelihood factor, based on component age, coating life in Table A.14, and the final ECSCC severity index, is calculated as follows:

$$\text{Likelihood Factor} = \text{SVI} * (\text{component age} - \text{coating life})^{1.1}$$

Note that the component age is based on the original in-service date.

The corresponding likelihood ratings for carbon and low allow steels are given in Table A.10. The lowest likelihood is associated with the lowest likelihood factor score.

~~Stainless Steel External Chloride Stress Corrosion Cracking Under Insulation~~

Table A.11- ECSCC Base Susceptibility

External Environment	Dry	Mild	Moderate	Severe
< 120 °F (< 49 °C)	None	None	None	None
120 to 200 °F (49 to 93 °C)	Low (1)	Medium (2)	High (3)	High (3)
200 to 300 °F (93 to 149 °C)	None	Low (1)	Medium (2)	High (3)
> 300 °F (> 149 °C)	None	None	None	None

Table A.12- ECSCC Adjustment Factors

Insulation Complexity	Minimal penetrations and branches	Some penetrations and branches	Many penetrations and branches
	-1	0	+1
Chloride Free Insulation		Yes	No
		-1	0
Insulation Condition	No sign of damage or standing water	Average condition with some deficiencies	Damaged condition with some deficiencies.
	-1	0	+1

Table A.13- ECSCC Severity Index

ECSCC Severity Index	None	Low (<=1)	Medium (2)	High (>=3)
	NA	1	10	50

SVI				

Table A.14- Coating Life (yrs)

Coating Life (years)		None or Unknown	General Coating	Quality Coating
		0	8	15

Table A.15- ECSCC Likelihood

Likelihood Class Factor	**Likelihood Class Number**	**Likelihood Class Descriptor**
< 3.27	1	Highly Unlikely
< 32.7	2	Unlikely
< 327	3	Possible
< 3267	4	Quite Likely
>= 3267	5	Likely

ME NOTE: The draft ballot contains a new semi-qualitative likelihood assessment in Annex A, as discussed at the Spring 2024 meeting. During that meeting, a request was made from the task group for the content submitter to explain why this would be a good addition. This explanation is shown here for information purposes and not to be included in the document itself.

Proposal Summary

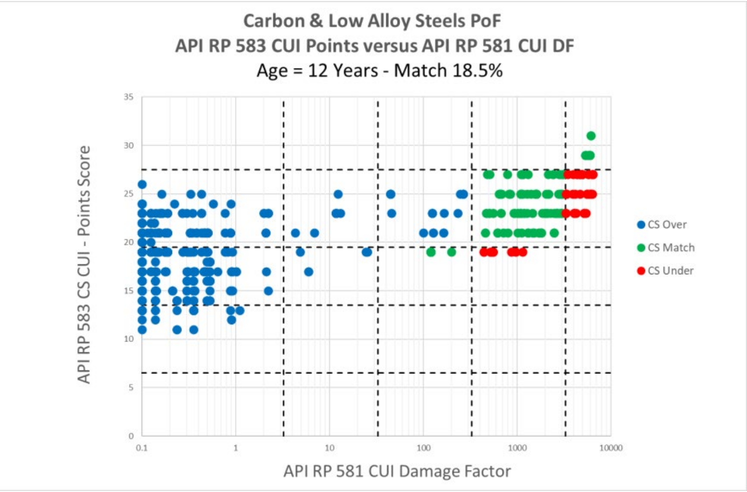
1. Proposal – add new method as second example in Annex A which is based on multiplication of factors, rather than the current method that is based on addition of factors.
2. Existing qualitative Annex A (current method) only matches the API 581 semi-quantitative approach 20% of time for carbon steel and 10% of time for stainless-steel over a 40-year life.
3. Current method over-estimates likelihood for first 20 years (too much inspection scope added) for on average 75% of the carbon & low alloy steel lines.
4. Current method over-estimates likelihood (too much inspection scope added) for 80% of the stainless-steel lines over the entire plant life.
5. Current method under-estimates likelihood for second 20 years (not enough inspection scope) for on average 40% of the carbon steel & low alloy steel lines.
6. New method matches the API RP 581 semi-qualitative method likelihood ratings > 95% of the time over a 40-year period for both CS and SS.
7. New method is an effective screening tool, requiring substantially less input and effort compared to API 581 and similar compared to the current method.
8. When method was changed from current method to new method for plant wide assessment on an LNG plant piping:
    a. for carbon and low alloy steels the average scope reduction was 90% in the first 10 years, 58% in the second 10 years and 20% in the third 10 years.
    b. for stainless steels the average scope reduction was 73% in the first 10 years, 64% in the second 10 years and 40% in the third 10 years.
9. New method would identify the initial inspection scope consistent with the API RP 581 semi-quantitative methodology while significantly reducing required inspection scope when compared with the current method.

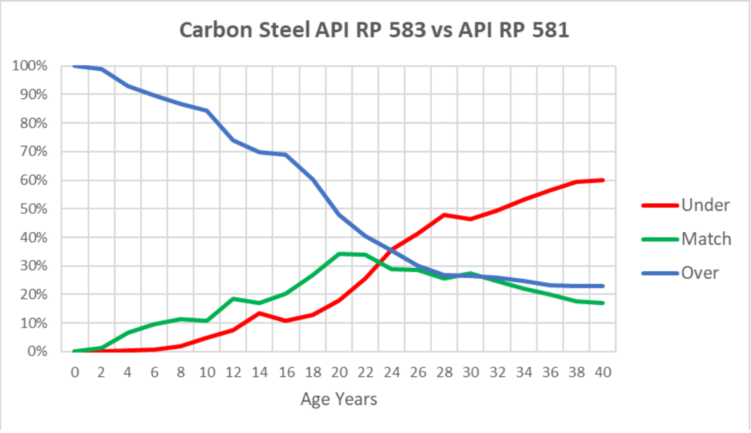
Basis

API RP 583 2nd Edition currently includes in Annex A an Example of a Qualitative Likelihood Assessment System. Annex A is not currently referenced anywhere within the text of API RP 583 2nd Edition. The most recent ballot for the 3rd Edition includes a new section 7.1.2 which references Annex A as an example of a simplified points-based qualitative approach for assessing the likelihood of CUI.

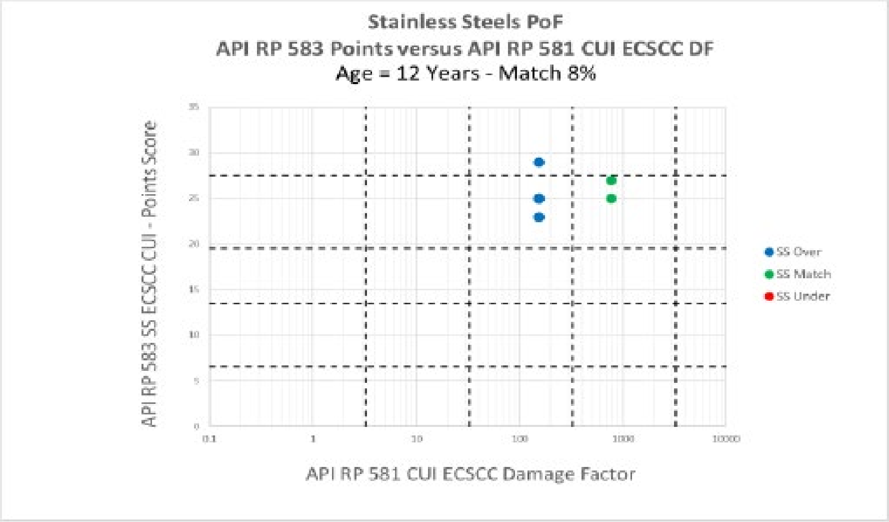
It is recognized that qualitative assessments are generally more conservative than quantitative methods and typically generate more conservative mitigation and inspection plan recommendations. The assessment method in Annex A was compared to the semi-quantitative method outlined in API RP 581 (see attached presentation) based on an evaluation of an LNG Plant piping line list.

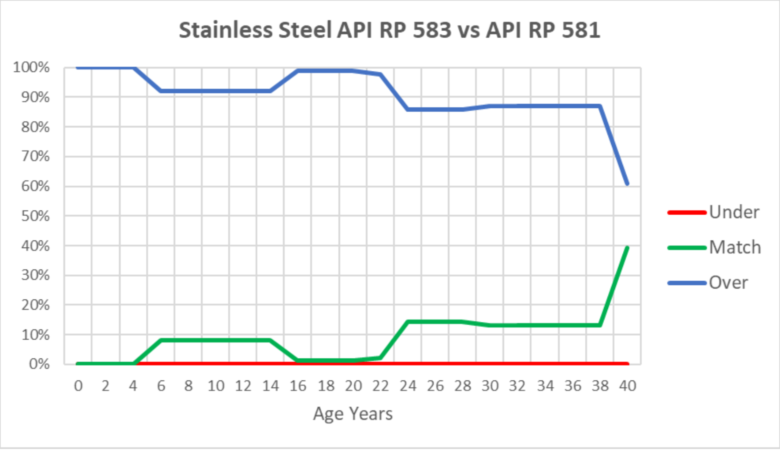
The carbon & low alloy steel likelihood assessments were found to be overly conservative with the likelihood rating estimates only matching the API RP 581 likelihood ratings approximately 20% of the time over a 40-year period. The qualitative method over-estimates early in plant life and under-estimated later in plant life.





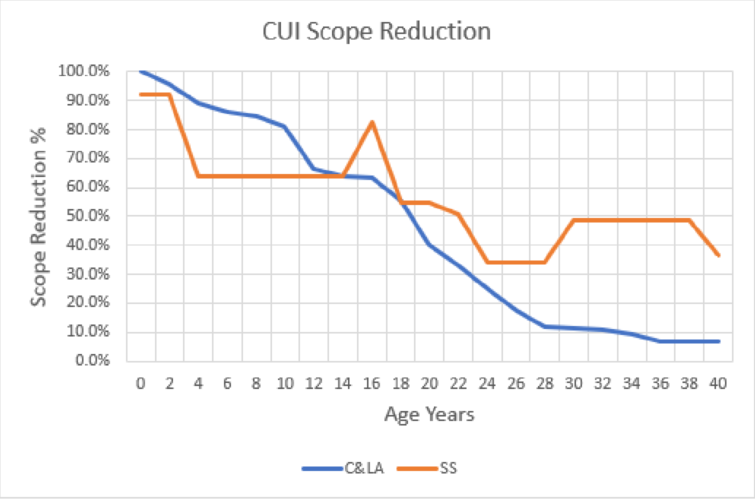
The stainless-steel likelihood assessments were found to be overly conservative with the likelihood rating estimates only matching the API RP 581 likelihood ratings approximately 10% of the time over a 40-year period. The qualitative method generally over-estimates with the best match 40% but after 40 years' service.





An inspection plan developed using the qualitative method would result in much more conservative inspection plans resulting in larger inspection scopes and associated costs when compared with inspection scopes developed using the API RP 581 methodology.

The exact scope reduction achieved by using the API RP 581 methodology compared with the qualitative method is dependent on the LNG Plant age at which the assessment was completed. For carbon and low alloy steels the average scope reduction was 90% in the first 10 years, 58% in the second 10 years and 20% in the third 10 years. For stainless steels the average scope reduction was 73% in the first 10 years, 64% in the second 10 years and 40% in the third 10 years.



A simplified semi-quantitative score-based likelihood methodology has been proposed as an addition, or replacement, for Annex A. The revised method for carbon & low alloy steels matches the API RP 581 semi-qualitative method likelihood ratings > 95% of the time over a 40-year period. The revised method for austenitic stainless-steels matches the API RP 581 semi-qualitative method likelihood ratings 100% of the time over a 40-year period as it uses the same methodology as API RP 581. Note that neither the simplified semi-quantitative method nor the points scoring method consider inspection results.

The simplified semi-quantitative approach can be effective for initial screening of units/equipment and may prove beneficial when attempting to prioritize where to begin a quantitative methodology.

Where the API RP 581 semi-quantitative methodology is to be used to include the number of inspections and their inspection effectiveness in the risk assessment the simplified semi-quantitative likelihood methodology aligns well with the API RP 581 methodology before inspections are considered.

Darryl Godfrey
Principal Engineer

Annex B

(informative)

Examples of Insulation Techniques for Various Applications

B.1 General

Figures B.1 through B.10 show a variety of designs to insulate a variety of components.

B.2 Cold Service Applications

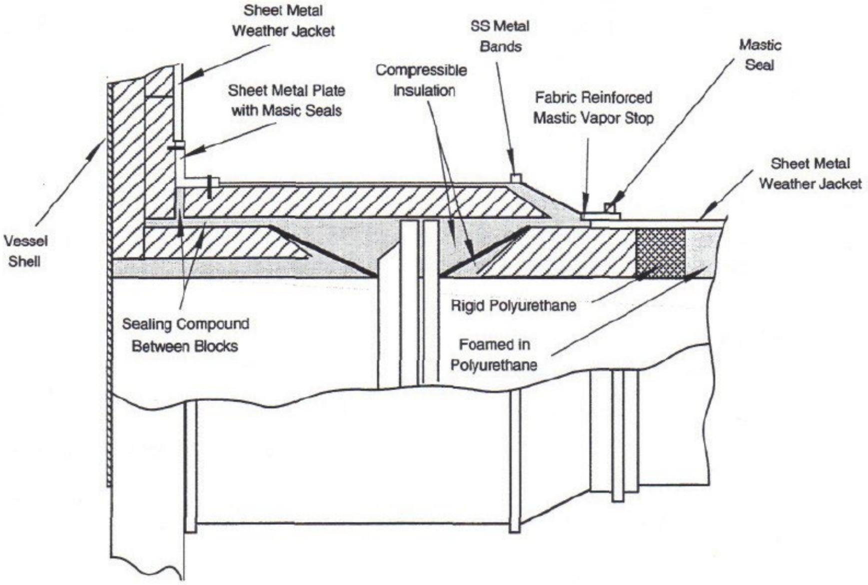
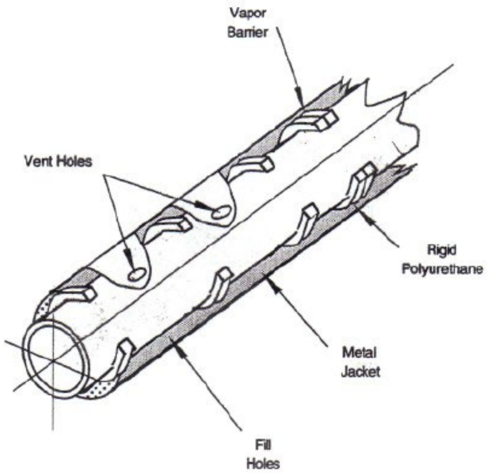


Figure B.1—Method of Insulating Nozzles and Manways



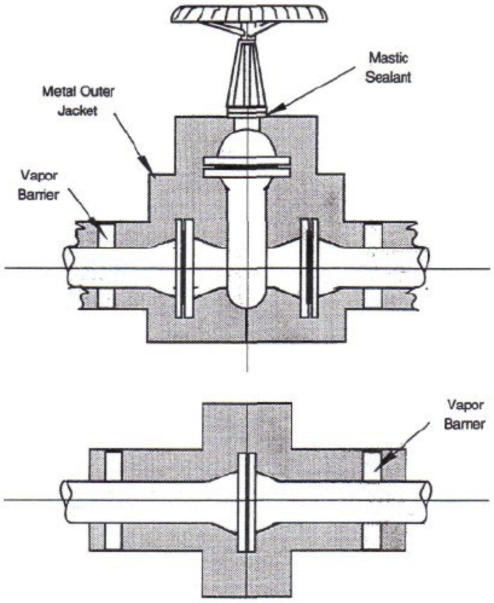
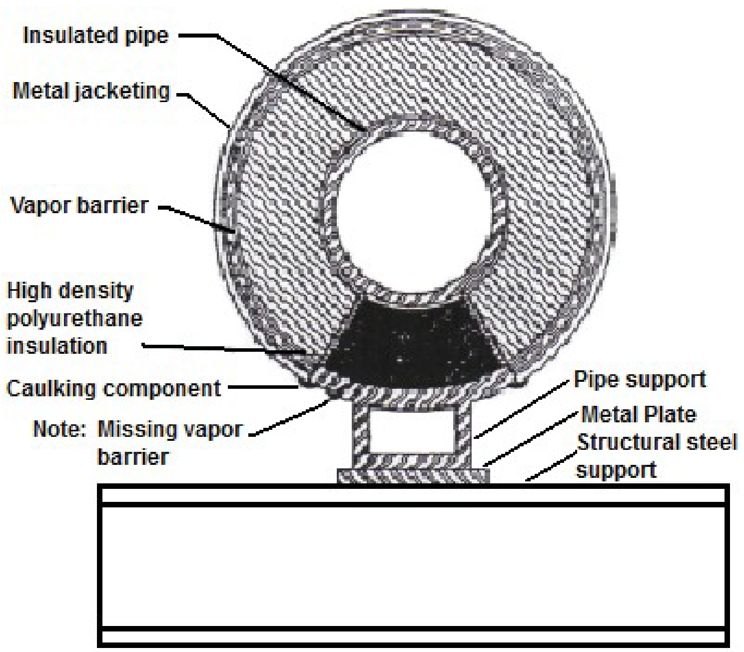


Figure B.2—Method for In Situ Polyurethane Foaming of Straight Pipe and Valve/Flange Boxes



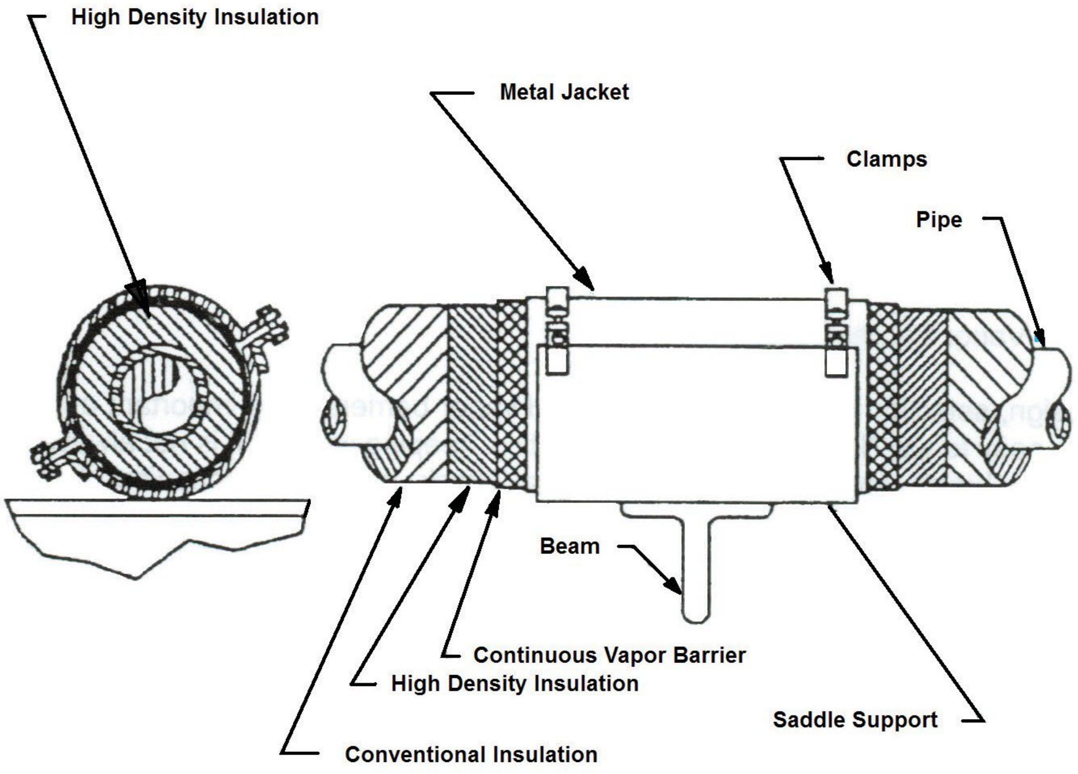


Figure B.3—Method for Insulating Pipe Support with and without Continuous Vapor ~~Barrier~~Retarder

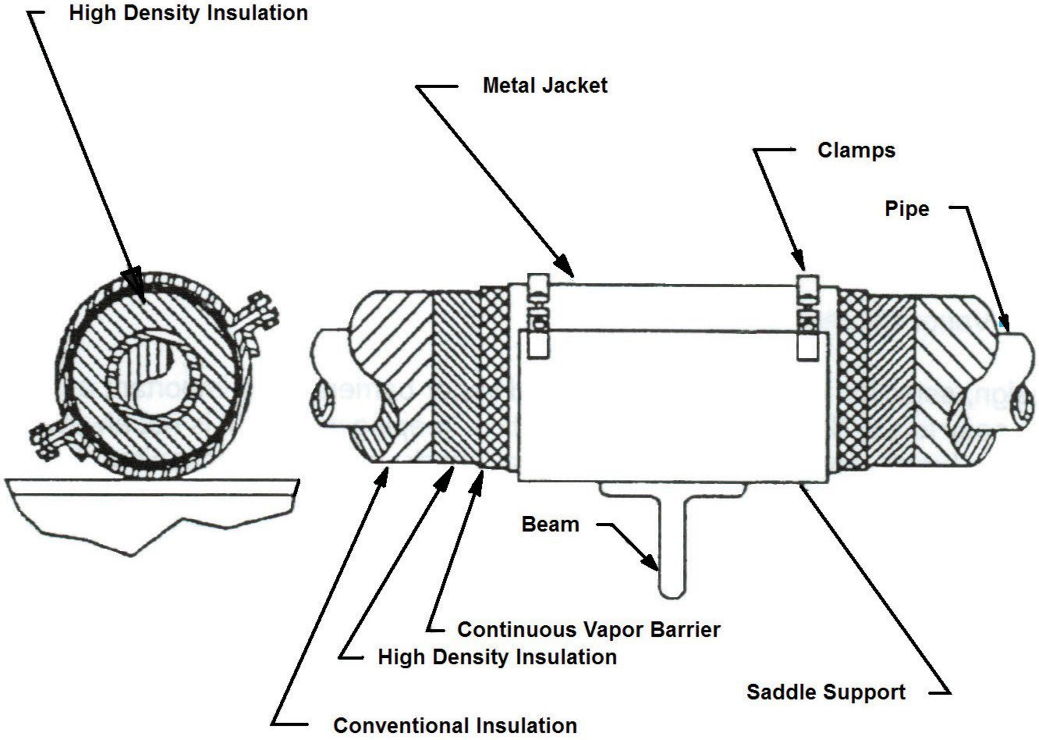


Figure B.4—Method for Insulating Miscellaneous Attachments

B.3 Hot Service Applications

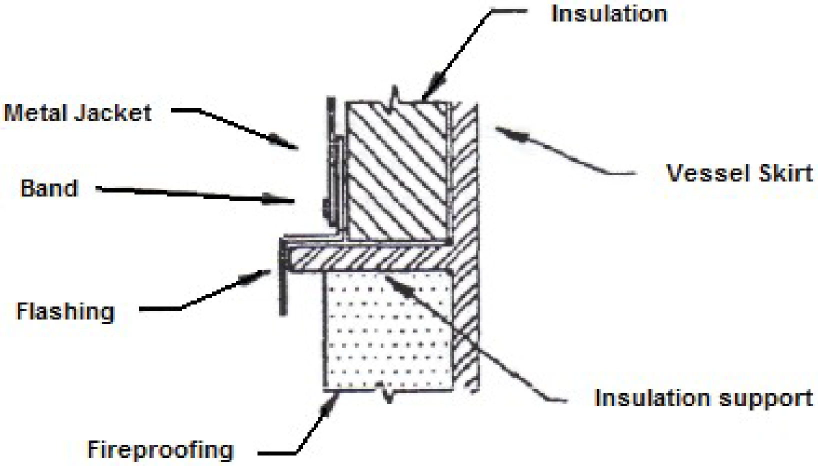
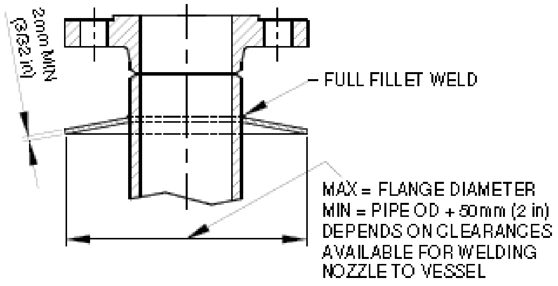
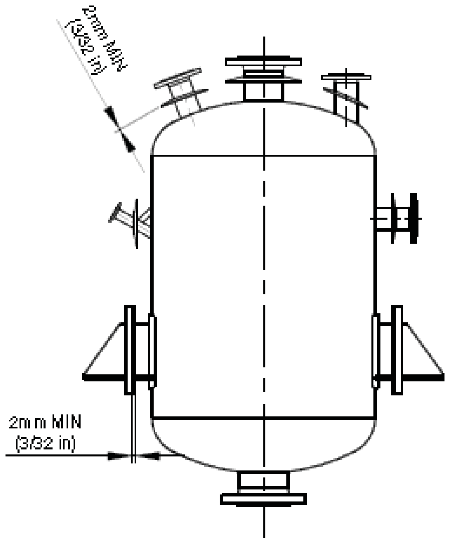


Figure B.5—Method for Insulating Vertical Vessel Bottom Support Ring



DIMENSIONS OF SEALING DISC



SEALING DISCS INSTALLED
IN DIFFERENT LOCATIONS

Figure B.6—Method of Diverting Water Away from Critical Locations

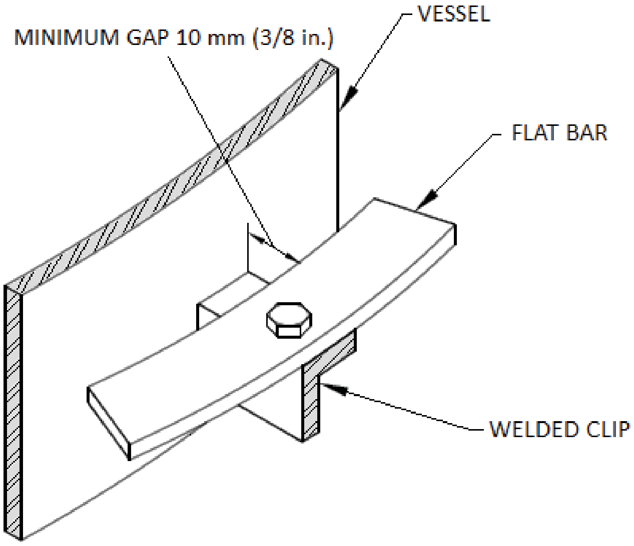


Figure B.7—Method of Avoiding Water Buildup at Insulation Supports

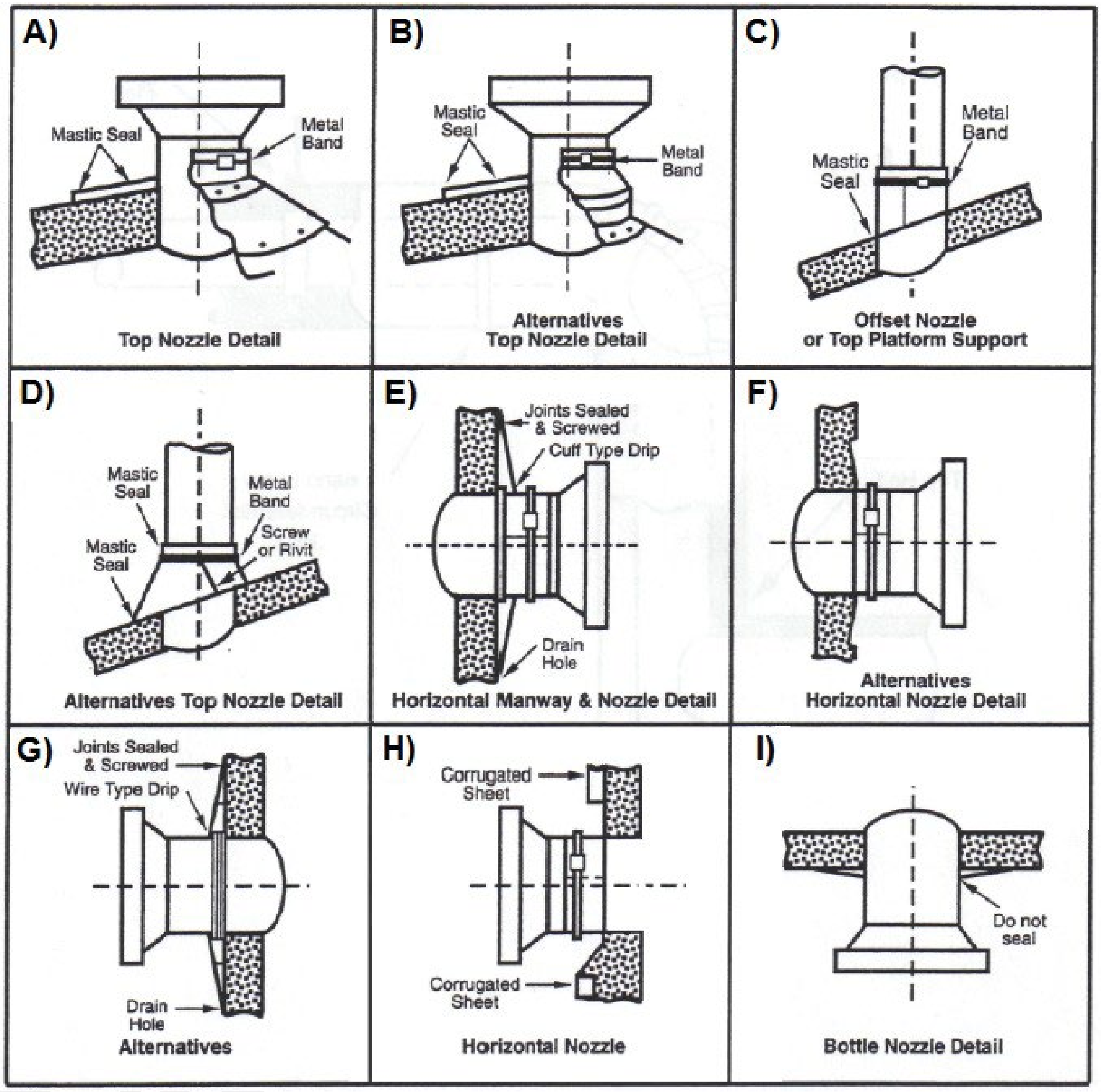


Figure B.8—Method of Avoiding Water Buildup for Vessel Nozzles and Attachments

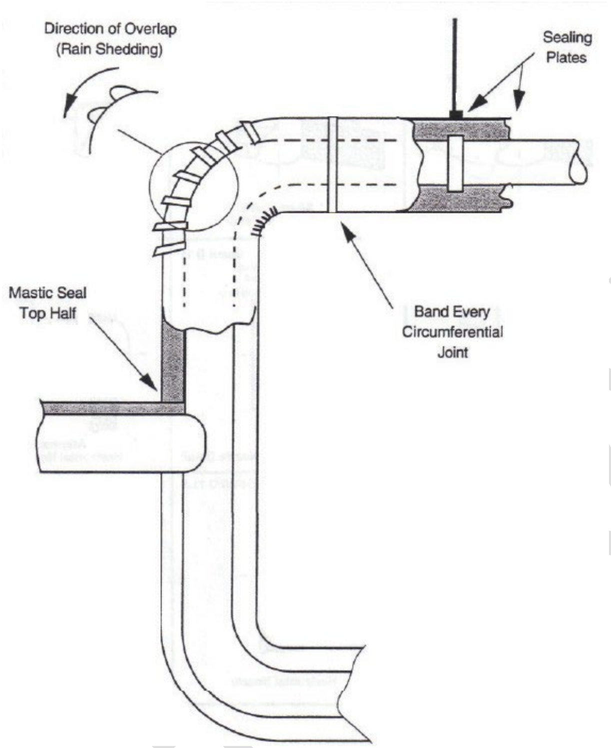

Direction of Overlap
(Rain Shedding)
Sealing
Plates
Mastic Seal
Top Half
Band Every
Circumferential
Joint

Figure B.9—Method of Avoiding Water Buildup for Piping

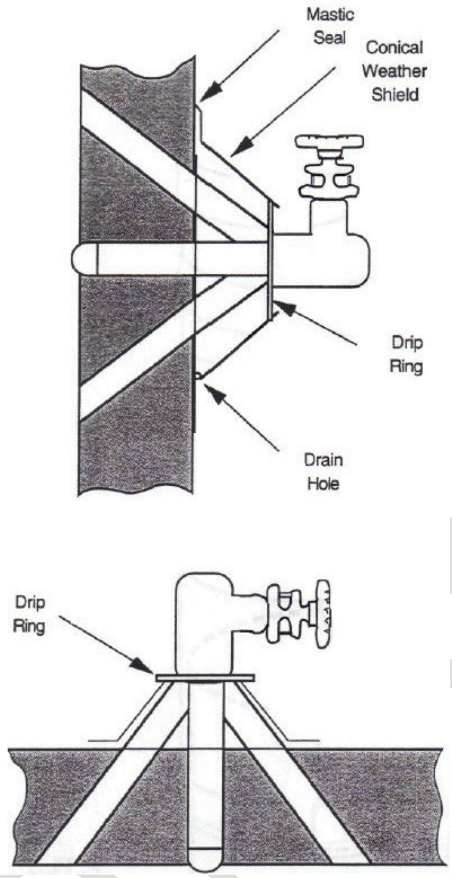


Figure B.10—Method of Avoiding Water Buildup for Horizontal and Vertical Gussets

Annex C

(informative)

Example CUI Visual Inspection Checklist

Tasks Prior To Visual Inspection

	Item	Comments
History	History Review	Review history on asset to determine prior repairs, inspections, and any other pertinent information related to health and equipment performance.
	Work Order Review	Review prior work orders to determine if there are any areas of interest or bad actors (i.e. Repeat repairs/activities needed to maintain health & function.)
	Prior CUI Inspection Review	Any prior CUI campaign activities that may be of interest for follow up or general inspector knowledge prior to field visual walkdown.
	CML/Internal Corrosion Review	Any areas where internal corrosion is occurring at an accelerated rate may coincide with CUI concerns. May provide insights into areas to perform NDE and possible to take additional care when executing discovery inspection(s) while in-service.
	CUI Equipment Specific History Drawing	Is there an eqiupment/system specific drawing(s) that show the CUI history? (Previous NDE areas, direct assessment areas, repaired areas…etc)
Environment	External Environment Determination	Inside Building/Covered, Arid Region, Temperate Region, Coastal/Marine Region…etc

Field Visual Inspection (No Insulation Removal)

	Item	Measure	Comments
perational Info.	Process Service	XX	Indicate process service.e.g., Process Gas, recycle oil, produced water…. etc)
	Line Size	#	Indicate nominal pipe size.
	Line/Equipment Temperature	Degrees F	Actual temperature of steel surface at time of inspection. Check with Operations on historical trend(s).
	Line/Equipment Pressure	psig	Operating pressure of equipment at time of inspection. Check with Operations on historical trend(s).

	Internal Corrosion Rate	mpy	Maximum corrosion rate(s) within the equipment/system.
	Service Type (Continuous/Cyclic/Intermittent)	Cn/Cy/In	Determine if equipment/system is used continuously, cyclicly, or intermittently.
	Steam/Electric Traced	Y/N	If traced, leads to another level of scrutiny and evaluation for potential leaks or accelerated areas of localized corrosion.
Insulation/ Coating	Insulation Type	text	Denote insulation type. (i.e. Blanket, Mineral Wool, Calcium Silicate, Perlite, Foamglass.... etc)
	Estimated Insulation Age	yrs	Approximate age of insulation. If cannot be determined, assume original equipment.
	Estimated Coating Age	yrs	Approximate age of coating. If cannot be determined, assume original equipment.
Penetrations	Dents Present	Y/N	Denote areas where dents are present. Attempt to determine cause of dent(s) and if they are in need of repair (i.e. allowing moisture ingress)
	Tears/Punctures Present	Y/N	Denote areas where tears/punctures are present.
	Inspection Ports Present	Y/N	Are there any intentional inspection ports?
	Plugs at Inspection Ports Present	Y/N	If plugs are missing, attempt to determine the cause. (e.g., Not tethered, never installed)
	Surface condition at Inspection ports	text	What is the surface condition at the inspection ports?
	Moisture Present	Y/N	Identify where areas of moisture exist and attempt to determine where ingress point may be.
	Support Penetrations	Y/N	
	Branch Penetrations/Transitions	Y/N	
	# of total penetrations	#	Total # of penetrations on line segment, vessel, tank...etc.
	Missing Insulation	Y/N	Denote where missing insulation is present and type/amount. Not condition of exposed equipment and adjacent exposed insulation (i.e. Wet, dry, signs of staining...etc)
Weather Jacket Info.	Weather Jacket Lapped Correctly	Y/N	Identify area(s) where weather jacketing may be lapped incorrectly or may be at 12 o'clock position...etc.
	Weather Jacket Sloped Correctly	Y/N or N/A	Locations where sloping is required (i.e. Insulation support rings, vacuum rings...etc).
	Banding Spaced Properly	Y/N	Compare against standard engineering drawing(s) for correct specification.
	Penetrations Sealed Properly	Y/N	Are penetrations sealed against moisture ingress.
	Vertical Transitions Lapped Correctly	Y/N	Check for correct vertical lapping.
	Staining Present	Y/N	Is there staining present from dripping, environmental deposits, and/or own equipment?
	Bulges/Deformation Present	Y/N	Any buldges, sagging, or deformation present? If so, attempt to determine cause.
	Organic Growth Present	Y/N	Is there any organic growth present?

Environment	Local Wet External Environment	Y/N	Is this exposed to cooling tower overspray, steam or water leaks, water deluge systems, sweating, etc

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