8 Non Destructive Examination used to the Detection of Flaws in Vessels and Pipework

Table 1 - Detection and sizing capability of the main NDT methods

		NDT method					
		Visual Insp.	Penetrant testing	MPI	Eddy Current	Radiography	Ultrasonic testing
Detection Capability	Cracking (open to surface)	√*	√	√	√	√*	√
	Cracking (internal)					√*	√
	Lack of fusion					√*	√
	Slag / inclusions					√	√
	Porosity / voids					√	√
	Corrosion / Erosion	√				√	√
Sizing capability	Flaw location	√	√	√	√	√	√
	Flaw length	√	√	√	√	√	√
	Flaw height				√*		√
	Component thickness					√	√
	Coating thickness				✓		√

* Technique has some potential for these applications.

Table 2 - NDT method versus damage type

Damage to detect	NDE Method	Capabilities and Limitations
Internal Corrosion/Erosion	Visual Inspection (Vessels Only) - Internal	Good detection capability but requires internal access. Limited sizing capability (depth/ remaining wall thickness).
	Manual Ultrasonic Testing/ 0 °Probe - External	Generally good detection and sizing capability (can be poor if corrosion isolated, particularly the detection of pitting).
	Automated Ultrasonic Testing/ 0 °Probe Mapping - External	Very good detection and sizing capability (application limited to pipe sections/ vessel walls where simple manipulation can be facilitated). Corrosion maps allow accurate comparison of data between repeat inspections. Comparatively slow technique to apply.
	Continuous Ultrasonic Monitoring - External	Good detection and sizing capability (at specific monitoring locations).
	Profile Radiography (Piping Only) - External	Good detection and sizing capability but comparatively slow technique to apply.
Weld Root Corrosion/Erosion	TOFD - External	Very good detection and sizing capability (depth/ remaining wall thickness). Access to both sides of weld cap required.
	Manual/ Automated Ultrasonic Testing/ 0 °Probe - External	Good detection and sizing capability but requires extensive surface preparation i. e. removal of weld cap.
	Manual/ Automated Ultrasonic Testing/ Angle Probe - External	Detection and sizing capability but can be unreliable.
Hot Hydrogen Attack/HHA (internal)	Ultrasonic Testing - External 0 °Probe/ High Sensitivity	Detection capability/ base material but can give false indications. Use of mapping system facilitates monitoring. For welds, removal of cap is required.
	Angle Probe(s)/ Medium Sensitivity	Detection capability/ welds but cannot detect microscopic stages of HHA. Use of automated system facilitates monitoring of macro-cracking.
	TOFD	Detection capability/ welds although discrimination between micro- cracking and other weld defects a problem. However, establishment of a base- line facilitates monitoring of micro-cracking.

Damage to detect	NDE Method	Capabilities and Limitations
Hydrogen Pressure Induced Cracking (HIC, Stepwise Cracking)	Ultrasonic Testing - External 0 □probe - 45 □angle probe	Good detection at later stages, but there are no proven early warning (susceptibility to cracking) tests for on- site inspection.
Creep Damage	Surface Testing	Magnetic measurements of Barkhausen noise, Differential Permeability or Coercivity are possible but also affected by other parameters e. g. stress and heat treatment. Surface Replication can be used to examine microstructure.
	Ultrasonic Testing - Attenuation/ loss of back wall echo - Backscatter - Velocity measurement	Methods developed for detection of early stages have not been proven in the field. Standard ultrasonic testing techniques are suitable at later stages.
Fatigue Cracking (Internal/ External)	Magnetic Particle Testing	Good detection capability but requires access to fatigue crack surface. Good length sizing capability. Some surface preparation usually required.
	Penetrant Testing/ Eddy Current	As above, for non- magnetic materials.
	Ultrasonic Testing/ Angle Probe(s)	Good detection and sizing capability (length and height), enhanced by use of automated systems - TOFD gives very accurate flaw height measurement and allows in-service crack growth monitoring.
	ACFM (can be used in- lieu of surface techniques stated above)	Good detection capability but requires access to fatigue crack surface. Length and good depth sizing capability. Unlike Magnetic Particle does not usually require surface preparation and can be used through coatings. Better for inspecting welds than Eddy Current.
Stress Corrosion Cracking/ SCC (Internal/ External)	Surface Testing	Magnetic Particle (not austenitic)/ Eddy Current (not ferritic) techniques - Good detection capability but access required to crack surface. Techniques require plant shutdown.
	Ultrasonic Testing - External	Fair detection capability; can be used on-line. Specialist techniques have some capability to determine crack features (orientation and dimensions (inc. height)).
	Acoustic Emission - External.	On- line detection of growing SCC in large component systems too complex to be inspected by other techniques. Extraneous system noise can produce false indications.

8.1 Techniques that meet the Requirements of the WSE in the Detection of Associated Flaws

Table 1 identifies the method(s) most appropriate for the detection of specific deterioration types and the sizing capability associated with each method. Table 2 expands on Table 1 for some of the specific deterioration types identified, i.e. cracking and corrosion/erosion.

8.1.1 Visual Inspection (VT)

Visual inspection, with or without the use of optical aids, is performed with the aim of detecting surface-breaking flaws. There are a variety of optical aids available to the visual inspector ranging from simple hand-held magnifiers to specialist devices such as fibre-optic endoscopes for the inspection of restricted access areas. The capability of visual inspection is heavily dependent on the surface condition of the component and the level of lighting available.

Limitations - Fairly limited capability unless special optical aids are used. Method usually requires supplementing with other methods/techniques to confirm the presence of flaws and for sizing.

8.1.2 Penetrant Testing (PT)

In penetrant testing, liquid penetrant is drawn into surface-breaking flaws by capillary action; application of a developer draws-out the penetrant in the flaw producing an indication on the component surface. Penetrant testing is a low-cost method to apply and is very fast (large area coverage).

Penetrant testing can be applied to any non-porous clean material, metals or non-metals, but is unsuitable for dirty or very rough component surfaces. Red-dye penetrant is the most commonly used; fluorescent penetrants are used when maximum flaw sensitivity is required. Penetrant testing can be fully automated, however, in the field, the method is manually applied.

Limitations - Can only detect flaws open to the surface (the component surface on which the penetrant is applied). In addition, the flaw must not be filled with foreign material as this prevents the penetrant from entering the flaw. Cannot determine flaw through-thickness dimension.

8.1.3 Magnetic Particle Inspection (MT or MPI)

In MPI, the component is magnetised either locally or overall. If the component is sound the magnetic flux is predominantly inside the material, if, however, there is a surface-breaking flaw, the magnetic field is distorted, causing local flux leakage around the flaw. The flux leakage is displayed, by covering the surface with very fine iron particles, usually suspended in a liquid. The particles accumulate at the regions of flux leakage revealing the flaw as a line of iron particles on the component surface. MPI is applicable to all metals that can be magnetised. With MPI, it is important to ensure that the direction of the magnetic flux is appropriate for the flaws expected. A variety of equipment is available, the most common method of magnetisation being the application of a permanent or electromagnet (AC yoke) to the component surface. The equipment is manually operated.

Limitations - Can only detect flaws in ferromagnetic materials. Can only detect surface flaws (some sub-surface capability exists with this method but detection can be unreliable). Cannot determine flaw through-thickness dimension.

8.1.4 Eddy Current (ET)

In eddy current testing, a coil carrying an AC current is placed close to the component surface. The current in the coil generates circulating eddy currents in the component close to the surface and these in turn affect the current in the coil by mutual induction. Surface-breaking flaws and material variations in the component affect the strength of the eddy currents. Therefore, by measuring the resultant electrical changes in the exiting coil, flaws etc. can be detected. Eddy current testing is applicable to all electrically conducting materials. Prior to their use eddy current systems require calibration, usually on test pieces. With this method of testing, sensitivity to flaws can be very high. The equipment is manually operated.

Limitations - High level of operator skill required to interpret signals. Spurious indications can result from (i) local variations in material permeability (especially near welds), and (ii) probe lift-off (on rough surfaces). Can only really detect surface flaws (some sub-surface capability does exists but detection can be unreliable). Limited capability for determination of flaw through-thickness dimension.

8.1.5 Radiography (RT)

In radiographic testing, a source of X or gamma radiation is used to produce an image of the component on photographic film (by placing the radiation source on one side of the component and the film on the other). Following exposure to radiation, the film is then processed and then viewed on an illuminated screen for visual interpretation of the image. Radiography gives a permanent record (the exposed film), which is a major advantage of the method, and is widely used to detect volumetric flaws (surface and internal).

X-ray equipment ranges from about 20kV to 20MV (the higher the voltage the greater the penetrating power of the radiation and the greater the thickness of component that can be tested). Gamma radiography is carried out using radioactive isotope sources (e.g. Cobalt-60, Iridium-192) although its sensitivity is generally less than that achievable by X-ray radiography. It is widely used for fieldwork because of its greater portability.

Limitations - Limited capability for the detection of (planar) flaws that are not oriented parallel to the radiation beam, e.g. lack of side-wall fusion. Cannot determine flaw through-thickness dimension. For on-site testing, restricted access to a controlled area is required.

8.1.6 Conventional Ultrasonic Testing (UT)

In ultrasonic flaw detection, a beam of high frequency sound (MHz range) from a small probe is used to scan the component material for flaws. This method of testing is used to detect both surface and internal flaws (planar and volumetric). In its simplest form, a small hand-held probe connected to a flaw detector (oscilloscope) is coupled to the component surface. By scanning the probe and observing the response on the flaw detector screen (the A-scan display) the location of flaws can be determined and their size estimated. By suitable design of probe, ultrasonic beams can be introduced into the component material at specific angles. Generally, a single probe acts as both transmitter and receiver of ultrasound, allowing inspection from one side of the component only (the single probe pulse-echo technique). As well as this technique (the most common) there are many other techniques – tandem, through-transmission and Time of Flight Diffraction/TOFD (described in specialist NDT techniques later). Most fine-grain metals can be ultrasonically tested, up-to large thicknesses, without difficulty. Prior to their use ultrasonic systems require calibration. With this method of testing, sensitivity to flaws can be very high. Considerable operator skill is required to interpret the A-scan displays. The majority of equipment is manually operated, however, for certain applications, complex multi-probe systems are used with computerised data acquisition/processing, display and analysis.

8.2 Specialist NDT Techniques

In this section, some of the specialist NDT techniques are described.

8.2.1 Alternating Current Field Measurement (ACFM) Technique

ACFM is an electromagnetic technique used for the detection and sizing of surface flaws in metallic components. The technique does not require any electrical contact with the surface of the component being inspected, and as such, can be used to inspect through coatings of various thickness and material. ACFM works by inducing a uniform electric current (AC) into the component; the presence of any surface flaw disturbs this uniform field, and measurement of the associated magnetic fields parallel to the flaw and perpendicular to the component surface allows flaw detection and sizing using specialist probes, instrumentation and software. In its simplest form, ACFM involves the use of a single hand-held probe, which contains the field induction and the field measurement sensors. The probe is connected to an ACFM instrument, which is computer controlled, providing data display and recording. ACFM is usually deployed manually but can be automated. Probes with multi-element arrays for large area coverage are available as well as probes for high temperature applications. ACFM can be used to inspect a variety of simple and complex welded components (Note: when used on carbon steel components, ACFM is only suitable for the detection of surface-breaking flaws; while for some non-magnetic materials, a sub-surface capability exists). ACFM provides information on flaw length and depth and can be used through coatings up to 5mm thick. Because flaw detection and sizing is based on the theoretical analysis of the measured signals there is no need for prior calibration. Probability of detection

(POD) results obtained for ACFM indicate a similar performance to Magnetic Particle testing, but with fewer false calls.

8.2.2 Alternating Current Potential Drop (ACPD) Technique

ACPD is an electrical resistance technique that can be used for the sizing of surface breaking flaws in materials that are electrically conductive. ACPD works by applying an electrical potential between two contacts attached to the component surface and measurement of the difference in resistance between a second pair of contacts placed firstly across sound material adjacent to the flaw and then across the flaw itself. The increase in resistance due to the flaw is then directly proportional to the height of the flaw from the surface. Whilst the ACPD technique is capable of accurate sizing, results are greatly affected by:

- the length : height aspect ratio of the flaw - large aspect ratios giving the most accurate results, and
- the presence of conductive bridging material in the flaw which shortens the electrical path between the prods resulting in an underestimate of flaw height.

ACPD equipment is portable and simple to use.

8.2.3 Ultrasonic Time of Flight Diffraction (TOFD) Technique

TOFD is one of the specialist ultrasonic techniques now becoming widely used for the rapid detection and accurate sizing of flaws (flaw height). TOFD is a very sensitive two-probe technique that works by accurately measuring the arrival time of ultrasound diffracted from the upper and lower extremities of a flaw. Because TOFD relies upon diffraction from the flaw front for detection and sizing, flaw orientation is not an important consideration (as it is with the pulse-echo techniques that rely upon reflection).

With TOFD, best results are achieved with skilled operators and specialist equipment and software capable of generating high-resolution images of the component. A number of systems are commercially available. Scanning of the component can be performed in a variety of ways, from manual scanning with encoded positional feedback, for simple site applications, through to fully automated inspection for more hostile environments, scanning speeds of the order of 50mm/s are typical. TOFD is ideally suited to the following:

- Rapid 'screening' of simple weld geometries (probes placed either side of weld).
- 'Fingerprinting' of critical components.
- Critical assessment and sizing of flaws (accuracy for measurement of flaw height).

- Monitoring of flaw growth (accuracy for measurement of flaw growth)

Whilst TOFD is a very powerful technique some limitations do exist. For example, dead zones exist under the scanning surface and at the back surface that can obscure indications from a flaw thereby affecting detection and sizing performance. The depth of these zones is dependent on the probes and separation used for the inspection.

When used for weld screening, TOFD may not detect unfavourably orientated flaws such as transverse cracks. In addition, small flaws that are not serious can sometimes mimic more serious flaws such as cracks; because of this, characterisations based on TOFD alone should be treated with caution. When accurate flaw characterisation is needed, additional scanning using the pulse-echo technique will often be necessary.

8.2.4 Automated Ultrasonic Pulse-Echo Technique

The most widely used ultrasonic technique is the pulse-echo technique. In order to enhance the reliability of this technique, specialist automated systems can be deployed. These systems facilitate single/multiple probe inspection and provide images of the component via sophisticated data collection, processing and analysis software.

In reliability terms, the main advantage of these systems, over the use of manual inspection, is that they remove the operator from the 'front-end' of the inspection thereby assuring full inspection coverage via pre-programmed manipulation and couplant monitoring. Another main advantage, over manual inspection, is the ability of automated systems to monitor component degradation via comparison of stored data/component images. Automated pulse-echo is ideally suited to the following:

- Weld inspection (using multiple probes)
- Corrosion Mapping/Monitoring (using a single probe)

Relatively new to the field of engineering inspection, but gaining acceptance, is Phased Array. With this pulse-echo technology it is possible to quickly vary the angle of the ultrasonic beam, to scan a component, without moving the probe itself -allowing multi-angle inspection from a single probe position. When applied to the inspection of welds, for example, a number of advantages are afforded:

- Reduction in the number of probes/scans required (reduced inspection time)
- Increased coverage for restricted access areas
- Optimised inspection (using for e.g. different wave modes, beam focusing).
- Potentially easier interpretation of images of the component inspected.

With automated ultrasonic inspection, the collected data is usually presented in one or more of the following ways:

- **B-scan presentation**: the display of the results of ultrasonic examination showing a cross-section of the component. This presentation is normally associated with sizing of through-wall flaws. (This presentation can also apply to TOFD inspection).
- **C-scan presentation**: the display of the results of ultrasonic examination showing a plan-view of the component.
- **D-scan presentation**: the display of the results of ultrasonic examination showing a side-elevation, usually of a weld. This presentation is normally associated with the length sizing of flaws, and with the screening of welds using TOFD.

(Note **A-scan presentation** is the display on an ultrasonic flaw detector used for manual inspection).

8.2.5 Spark Testing Technique

The high-voltage spark testing technique or 'holiday' detection technique as it is often called, can be used to locate flaws in insulating coatings on conductive substrates. In combination with ultrasonics, for thickness measurement and the detection of de-laminations, spark testing is used to test the integrity of the welded joints of thermoplastic liners of glass reinforced plastic (GRP) storage tanks. The technique works by applying a high-voltage to a suitable probe with an earth return connected to the conductive substrate (for lined GRP this substrate is included in the design of the joint). As the probe is passed over the surface of the coating a spark at the contact point and an audible alarm in the detector indicates a flaw. Spark testing equipment is portable and simple to use. A large variety of probes are available with selection dependent on the particular testing application.

9 Corrosion Mechanisms assessed and where they apply to each System

9.1 Corrosion Mechanisms – General Description

Internal corrosion:

In hydrocarbon process systems the main internal threat to carbon steel pipework is through CO2, sweet corrosion and H_2S, sour corrosion. In seawater systems the main internal threat is oxygen corrosion in the presence of chloride ions.

9.2 Carbon Dioxide Corrosion

Carbon dioxide in the gas phase partially dissolves in produced water forming carbonic acid, which is corrosive to carbon steel, with corrosion proceeding via the reduction of hydrogen ions. Corrosion caused by carbon dioxide is addressed by the inclusion of a corrosion allowance to compensate for wall thickness loss in the carbon steel, injection of chemical inhibitor, application of anti corrosion coatings and by the use of inherently corrosion resistant materials.

9.3 Dead Leg Corrosion

Definition: A dead leg is a section of pipework or vessel which contains hydrocarbon fluids and / or water under stagnant conditions, or, where there is no measurable flow. More precisely a dead leg is any segment of piping extending below the horizontal plane of the pipe, which can become

a trap for water, sediment or other corrosive materials. Furthermore, a broad definition of a dead leg includes dead ends, which refer to piping that does not extend below the horizontal plane of the pipe yet contain stagnant fluids.

Dead legs may be locations of long term stagnation or "operational" dead legs. The latter are only sometimes stagnant for operational reasons,

e.g. the use of only one export pump at a time.

The two key causes of corrosion in dead legs are **(1)** bacteria, usually sulphate reducing bacteria (SRB), which proliferate in stagnant, oxygen free water where appropriate nutrients are available. They oxidise organic components in water and reduce ions to produce H2S as part of their metabolism, and **(2)** under deposit corrosion caused by the presence of sand or corrosion products and where the mechanisms can vary. In oxygenated systems, anodic areas can exist under deposits due to differential aeration. In production systems, a number of factors can be involved, such as locally high acidity within pits and the reduced ability of inhibitors to penetrate deposits.

9.4 Sour Service, Hydrogen Sulphide Corrosion

The production of hydrogen sulphide increases the risk of corrosion cracking of both carbon and stainless steels, and non-ferrous metals. The NACE MR-0175 standard defines thresholds for sour service and specifies materials that are resistant to cracking.

9.5 Categorisation of Sulphide Stress Corrosion Cracking

Degradation of materials caused by hydrogen sulphide are primarily Sulphide Stress Corrosion Cracking (SSCC). These can occur above particular partial pressures of hydrogen sulphide. This is normally mitigated against at the design stage through fabrication of all materials in accordance with NACE MR-0175 sour service specification. The NACE guidelines define sour service as when the partial pressure of hydrogen sulphide in a wet gas phase exceeds 0.05 psia. Where sufficient reliance can be given to the chemistry of the produced water, the sour service guidelines produced by European Federation of Corrosion Engineers[3] can be applied. These define three domains as non-sour service (1), transition region (2) and sour service (3). In the absence of reliable production chemistry data assessments will be based upon the suitability of the material for NACE sour service.

9.6 Categorisation of Hydrogen Induced Cracking (HIC)

Hydrogen induced cracking occurs as a result of the diffusion of monatomic hydrogen into the metallic structure of the vessels and pipework. This monatomic hydrogen combines at discontinuities in the material, which can ultimately lead to failure through cracking.

9.7 Seawater, Injection Water and Cooling/ Heating Medium Corrosion

In seawater service corrosion is mainly a result of dissolved oxygen. In raw seawater systems, the normal method for control is through the use of internal linings, corrosion allowances on carbon steel and, more commonly in recent years, through the use of corrosion resistant materials. Biocide injection can also be performed to control gross fouling and microbial corrosion.

In injection water systems the main cause of corrosion is through dissolved oxygen and the presence of sulphate reducing bacteria (SRB's). Corrosion is controlled by maintaining a low dissolved oxygen concentration (typically deaeration and scavenging to 10 ppb and below), and through the use of corrosion allowances when carbon steel is used. Microbial corrosion is controlled by the injection of biocide. The threat of microbial corrosion can be assessed by reference to annual microbial surveys.

In the closed cooling water system oxygen corrosion is controlled by the use of corrosion allowances and corrosion inhibition where carbon steel is used.

9.8 Corrosion due to Production Chemicals

Concentrated chemicals such as corrosion inhibitors can be corrosive to carbon steel and can lead to rapid localised metal loss. This is mitigated against by the use of corrosion resistant or coated materials for the storage and injection facility and the use of injection quills to prevent neat inhibitor from contacting the internal walls of carbon steel pipework.

9.9 Microbial Corrosion

Microbial corrosion is a mechanism initiated or accelerated by micro-organisms. Corrosive attack occurs beneath and adjacent to the microbial culture. Proliferation of micro-organisms tends to be greatest in areas of pipework where the flow is low and hence dead leg areas of pipework are especially prone to this form of attack. The bacteria proliferate through the assimilation of nutrients from the environment oxidising them and giving off the by-products for corrosion to occur. The most common bacteria are sulphate reducing bacteria (SRB's) which utilise the sulphate ion for the assimilation of organic matter.

9.10 Erosion

Erosion is the direct removal of a material by the mechanical action of a flowing environment, literally wearing away the metal surface. Erosion-corrosion is when protective corrosion product films are removed by the erosive action of a flowing environment. This exposes the underlying metal to the corrosive environment, resulting in corrosion at an accelerated rate. Erosion and erosion-corrosion are encountered when the mixture velocity exceeds certain critical limits. A material, which is known to be susceptible to erosion, is Cunifer pipework.

Sand content is generally at it's highest during the start-up of wells. The best way of minimising sand production is through monitoring during this "bean-up" operation to minimise sand production. Sand monitoring and wall thickness checks can be performed to effectively manage sand problems in choke valves and manifold pipework.

9.11 External Corrosion

Oxygen and chloride in the presence of moisture primarily cause external atmospheric corrosion. Prevention of external corrosion is usually afforded by the application of anti-corrosion coatings. For certain grades of stainless steels, exposure of the bare metal to chloride containing atmospheres can lead to pitting corrosion and stress corrosion cracking but they are assumed to be resistant to general corrosion.

All the external steelwork in the topside structure and equipment has been protected by an anti-corrosion coating system to ensure that atmospheric corrosion is controlled to acceptable levels and the fabric of the platform is adequately maintained. The full coating system should also have been applied under any lagged sections of pipework. The assessment of susceptibility to external corrosion is carried out by assessment of the operating temperature of the line, its location and any documented inspection history. The latter typically include assessments of the external coating and any resultant external corrosion. Typically, lines operating at higher temperatures in exposed locations will encounter the highest corrosion rates.

9.12 Corrosion under Insulation

Where insulation or lagging is present, it can lead to accelerated corrosion rates due to the retention of water and the maintenance of warm conditions. Prevention is usually afforded by the application of anti-corrosion coatings and where achievable by the removal of lagging. If however lagging is required for process reasons the cladding must be maintained in good order to prevent water ingress. The threat of external corrosion underneath insulation (CUI) can be assessed on the basis of the temperature of the line and vessel. The API BRD 581[5] base resource document for risk based inspection has provided guidelines on the effect of temperature on corrosion rates beneath insulation in marine environments. Stainless and duplex steel lines are susceptible to localised corrosion at elevated temperatures. The concentration of salts beneath lagging or the presence of heat tracing can exacerbate corrosion under insulation. The threat of localised corrosion underneath insulation to normally corrosion resistant materials is temperature dependent (see later section on chloride pitting and stress corrosion cracking).

9.13 Creep

Creep is not considered to be a problem due to the relatively low temperatures of the facilities. Susceptibility to creep should be assessed upon the material temperature limits from the appropriate design code material requirements.

9.14 Fatigue

Vibration induced fatigue affects all areas of the platform. Recent studies and witnessed failures within the industry has highlighted the most susceptible area to be unsupported branch connections to main lines. Lines associated with sources of vibration such as rotating equipment will be at a higher risk of vibration induced fatigue failure i.e. pumps and compressors.

Temperature cycling leading to stress cycles can cause thermal fatigue. This is usually assessed when selecting materials of construction at the design stage.

9.15 Chloride Pitting and Stress Corrosion Cracking

Most grades of stainless steel are susceptible to localised chloride pitting corrosion and stress corrosion cracking (ClSCC) upon exposure to chloride containing atmospheres. Susceptibility to chloride pitting corrosion is greatest above the critical pitting temperature, which is material specific. This is typically of the order of 20°C for austenitic stainless steels such as AISI 316, and 50°C for duplex steels such as 2205. Susceptibility to stress corrosion cracking is greatest above temperatures of 50°C for austenitic stainless steels such as AISI 316 and 70°C for duplex grades. Prevention is by coating to prevent contact between the steel and the chloride.

Figure 1 - Examples of Dead Legs

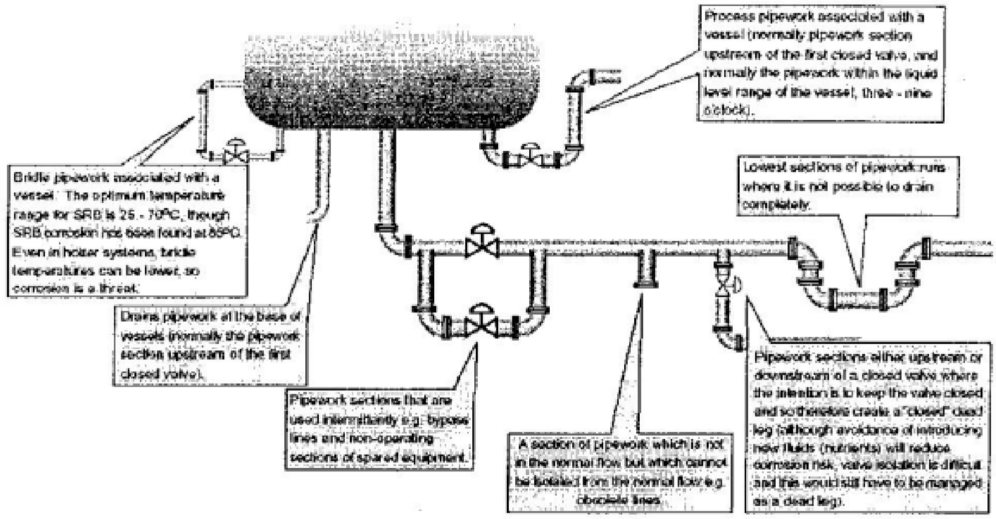

Table 3 Corrosion threats applicable by system

Corrosion Type	LPG Condensate	Oil Processing	Produced Water	Fuel Gas	Water Injection	Diesel storage & distribution	LP / HP Flare	Closed Drains	Oily Drains collection and disposal	Open drains	Compressed air	Potable water	Seawater	Chemical injection	Firewater and deluge	AFFF system	Lube oil	Hydraulic oil	Helifuel	Jetwash	Methanol	HP drilling systems
Internal																						
CO_2	√	√	√	√			√	√	√													
Dead leg		√	√		√	√	√	√	√	√										√		
Under deposit		√	√		√	√		√	√	√										√		
SCCC																						
HIC																						
Erosion		√			√								√							√		√
SRB		√	√		√	√	√	√	√				√							√		
Oxygen					√					√	√	√	√		√					√		√
External																						
General Corrosion / CUI	√	√	√	√	√	√	√	√	√	√	√	√			√	√				√	√	√
Fatigue		√			√												√			√	√	√
Cl pitting				√(2)										√		√(2)	√(2)	√(2)	√(2)			
Cl SCC				√(2)										√		√(2)	√(2)	√(2)	√(2)			

Notes:

All systems constructed from carbon steel u.n.o

Stainless Steel item only