

Factors to consider when managing the mechanical integrity of dead-legs on industrial facilities

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Preface

An incident at a UK refinery in 2017 brought into focus how the mechanical integrity of dead-legs is managed. Dead-legs are sections of piping connected to vessels or pipework that experience intermittent or no-flow conditions which can expose them to a number of degradation mechanisms. In this case, despite the refinery following industry inspection guidelines, severe localised corrosion resulted in a catastrophic rupture of a large diameter dead-leg riser to a safety valve and leakage of a large amount of boiling hydrocarbon into the surrounding plant.

Consequently, the UK Health and Safety Executive issued a safety alert to industry making various recommendations to prevent a similar occurrence at other sites. In response, EEMUA invited members to take part in a forum to discuss issues involved. This publication sets out the findings of the forum.

It is intended to complement company policies and procedures and assist facility personnel to safely manage dead-legs. It is intended to contribute towards good practice guidance.

Acknowledgements

This guidance is based on information discussed during a series of meetings of the EEMUA Dead-leg Forum made up of EEMUA members' representatives from refineries and chemical plants in the UK, Ireland and the Netherlands.. The guidance reflects the discussions and also reflects information from a questionnaire, published articles and papers on the subject.

Abbreviations/Acronyms used in this Guide

ALARP	As Low As Reasonably Practicable
AMPP	Association for Materials Protection and Performance
API	American Petroleum Institute
C&I	Control and Instrumentation
CCD	Corrosion Control Document
CoF	Consequence of Failure
COMAH	Control of Major Accident Hazards Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
CML	Condition Monitoring Location
CUI	Corrosion Under Insulation
EI	Energy Institute
FEMI	Fixed Equipment Mechanical Integrity
HF	Hydrofluoric Acid
HSAWA	Health and Safety at Work etc Act
HSE	Health and Safety Executive
IOW	Integrity Operating Window
ISO	Isometric drawings
KPI	Key Performance Indicator
LPG	Liquified Petroleum Gas
MIC	Microbiologically Influenced Corrosion, Microbial-Induced Corrosion
MoC	Management of Change
MPI	Magnetic Particle Inspection
NACE	National Association of Corrosion Engineers (now AMPP)
NDE	Non-Destructive Examination
NDT	Non-Destructive Testing
NFPA	National Fire Protection Association
NRV	Non Return Valve
OSHA	Occupational Health and Safety Administration
P&ID	Piping and Instrumentation Diagram
PAUT	Phased Array Ultrasonic Testing
PHA	Process Hazard Analysis
POD	Probability of Detection
PoF	Probability of Failure
PRT	Profile Radiographic Testing
PRV	Pressure Relief Valve

PSSR	Pressure Systems Safety Regulations
PSV	Pressure Safety Valve
PUWER	Provision and Use of Work Equipment Regulations
QA	Quality Assurance
RA	Risk Assessment
RBI	Risk Based Inspection
RP	Recommended Practice
SEA	Scale, Extent, Amount of inspection
SME	Subject Matter Expert
TAR	Turnaround (major plant outage)
TOFD	Time Of Flight Diffraction
UDC	Under Deposit Corrosion
UK	United Kingdom
USTM	Ultrasonic Thickness Measurement
UT	Ultrasonic Testing
WSE	Written Scheme of Examination

1 Introduction

Dead-legs in process plants have long been recognised as being at risk of failure mainly from corrosion or from freezing of accumulated water causing bursts; a significant number of failures have been documented over the years. Drains and low points where deposits can build up can be particularly prone.

The American Petroleum Institute has collated data on spills via its Pipeline Performance Tracking System (now the Pipeline Strategic Data Tracking System) which included facilities releases. An advisory in 2014⁽¹⁾ reported that, in facilities, over 96% of internal corrosion incidents occurred in areas of intermittent and no flow. This included both crude oil and refined products. Operator advisories since 2009 have highlighted dead-legs for special consideration of their integrity.

Degradation mechanisms in dead-legs are often substantially different to those in the main pipe and rates can be much more severe and the attack quite localised. The effort to manage the integrity of dead-legs is not trivial as there may be 100s to 1,000s of them on a process plant.

Operators in the UK have statutory duties under the Pressure Systems Safety Regulations⁽²⁾ and the Provision and Use of Work Equipment Regulations⁽³⁾ to maintain and inspect pressure equipment where deterioration can take place and under the Control of Major Accident Hazards Regulations⁽⁴⁾ “to take all measures necessary” to avoid major accidents, as well as general duties under the Health and Safety at Work etc Act⁽⁵⁾. Dead-legs are covered under these duties.

Industry guidance on the inspection of pipework including dead-legs is contained within API 570⁽⁶⁾, API RP 574⁽⁷⁾ and advice published by the Energy Institute⁽⁸⁾. These are regarded as relevant good practice by the UK Health and Safety Executive (HSE) for the purposes of reducing risks to as low as reasonably practicable (ALARP).

Despite the abundance of guidance and action taken by operators, failures have continued to occur. A recent incident at a UK refinery had the potential for a major fire and explosion. In the light of this, the UK HSE issued a Safety Alert in August 2019⁽⁹⁾, drawing attention to the generic problem and listing a number of actions required of process plant operators. The Alert is reproduced in Appendix A.

The industry guidance referred to above only provide general guidance for managing dead-legs; it requires individual companies to interpret their application and produce in-house procedures that are more specific to their plant and processes.

Different interpretation of industry guidance, different company procedures and practices and different experience of dead-leg issues, could, of course, lead to variation in the application of managing dead-leg integrity across industry. This was a subject of subsequent discussions within EEMUA’s User Inspectorates Committee.

This EEMUA publication addresses the areas referred to in the Alert and other important considerations. It provides general guidance in those areas, however, users of this publication should satisfy themselves that they are meeting the specific requirements of the alert in all cases.

1.1 Purpose

In response to the alert and discussions within EEMUA, refinery and chemicals members formed a dead-leg forum to facilitate information exchange; to ensure knowledge of the recent incident was effectively promulgated; to share between members their company approaches and programmes, developments in assessment and inspection; operations and management procedures and to fill any gaps in knowledge of good practice and assist its adoption.

1.2 Scope

The forum met on a number of occasions and identified a number of factors that deserved particular attention when managing the problem.

This publication provides a description of these factors as they currently stand – future updates may be published. It was not the role of the forum to provide technical solutions to issues (which are being dealt with by companies, possibly in conjunction with API committees), but to highlight areas to members where knowledge of different approaches would be beneficial to delivering good practice.

2 Incident at UK refinery

On 30 November 2017, at around 5 AM, an 8" line section catastrophically failed on an HF Alkylation plant's vertical line, positioned at the inlet to a PSV. The 8" vertical section, roughly 4.5 m long, served as a dead-leg branching off an 18" main line. This dead-leg was one of two similar ones adjacent to each other. The sister dead-leg was replaced in 2003. The failure mechanism was identified as localised corrosion due to condensation of HF acid. The HF acid vapour collects in the dead-leg and condenses as it travels up the uninsulated line corroding the pipe in a local region. The failed line was part of a surveillance programme for dead-leg pipework and was being monitored for corrosion by measuring the pipe thickness. However, the failure occurred between two condition monitoring locations on the inlet to the PSV.

2.1 Process and process equipment

The failure occurred on a hydrofluoric acid alkylate iso-stripper unit which produces a high octane component for petrol from a mixture of iso-butane and olefins. The plant had been in operation for many years, maintained and regularly inspected over that period. Typical operating conditions were 208 °C and 9.5 Kg/cm² (9.3 bar). The failure allowed the leakage of over 75 tonnes of boiling hydrocarbon to atmosphere; the resulting vapour cloud dispersed without igniting. Detectors around the process plant triggered an automatic emergency shut down of the unit.

2.2 Description of dead-leg failure

The fractured section, approximately 300 mm in length was discovered approximately 50 m away from its original location. The displaced section, located 2.6 m above the main header, had also split axially over its full length and was buckled (Figure 2-1). Subsequent ultrasonic thickness measurements (USTM) and physical measurements revealed that the locally thinned section had a minimum remaining wall thickness of 1.4 mm, down from a nominal thickness of 8.2 mm (8" Sch 40). Thickness readings taken away from the failed section at the upper and lower extremes of the dead-leg, showed them to be nearer to the nominal.



Figure 2-1 Photo showing the displaced section of line

2.3 Inspection regime

The failed dead-leg underwent regular inspections, with the interval determined by the corrosion rate or a maximum of 3 years, whichever was sooner. Over the 22 years in service, 18 separate inspection events were completed. The failed line section, in service since 1995, was inspected in accordance with API 570 requirements. There were four corrosion monitoring locations (CMLs) on the dead-leg, spaced across the top, middle, and bottom, all inspected via full circumferential USTM band scans. The minimum thickness recorded from the latest scans prior to the failure was 4.2 mm, giving an estimated corrosion rate of 0.18 mm/yr. The retiral alarm setting was 3 mm.

3 Dead-leg management guidance

In their safety alert, the HSE identified three publications they regard as relevant good practice for the purposes of reducing risks to as low as reasonably practicable (ALARP), particularly for process plant on establishments subject to COMAH. As noted previously, these are API 570, API RP 574 and an Energy Institute publication, Guidance for corrosion management in oil and gas production and processing. Each publication contains a section addressing dead-legs. Further details are provided in Appendix B.

The above industry guidance and the HSE Alert set out the basic approach to managing dead-legs. Essentially:

- Identify all dead-legs
- Eliminate where possible
- Risk assess taking account of dead-leg specific degradation mechanisms
- (In some cases apply operational mitigations)
- Inspect and replace as required
- Review

The industry management guidance is quite general and contains broad definitions – what is classified as a dead-leg, how many are inspected, how much is inspected and how frequently, may vary across industry.

3.1 Comparison of Dead-leg definitions

Table 3-1 compares the description of dead-legs presented in the above three publications. Descriptions from three other publications, API RP 581⁽¹⁰⁾, API RP 1188⁽¹¹⁾ and API RP 2611⁽¹²⁾, although not called up by HSE, are also presented.

Table 3-1 Comparison of Dead-leg descriptions

Publication	Dead-leg Description
API 570 In-service Inspection, Rating, Repair, and Alteration of Piping Systems	Components of a piping system that normally have little or no significant flow
API RP 574 Inspection Practices for Piping System Components	Components of a piping system that normally have no significant flow
Energy Institute Guidance for corrosion management in oil and gas production and processing	A section of pipework or vessel which contains hydrocarbon fluids and/or water under stagnant conditions (either permanently or intermittently), or where there is no measurable flow

Publication	Dead-leg Description
API RP 581 Risk-Based Inspection Methodology	A section of piping or piping circuit that is used only during intermittent services such as start-ups, shutdowns, or regenerative cycles rather than continuous service
API RP 1188 Hazardous Liquid Pipeline Facilities Integrity Management	Segments of a piping system in which fluid flow is negligible or intermittent, which includes piping no longer in use but still connected to the process (Note 1: Dead-legs are often created by isolation valves. Note 2: Dead-legs can include relief lines or other piping that does not operate on a regular basis. Also refers to piping configurations where water or sludge may accumulate)
API RP 2611 (withdrawn and replaced by API RP 1188 above) Terminal Piping Inspection - Inspection of In-Service Terminal Piping Systems [scope is liquid service]	Internal areas of a piping system that are isolated by valves or location having no flow for more than three consecutive months

As can be seen, all the descriptions in the publications are general and provide little if any detail of, for example: -

- What “little” flow may be – small percentage of design flow, a mass flow rate, a minimum velocity?
- What normally or intermittency may be – daily, weekly, monthly, yearly?
- Dimensional significance of dead-leg – diameter, length, length to diameter ratio, diameter ratio to main?
- Orientation – vertical off top or bottom of main, horizontal, angled upwards or downwards?

Examples of dead-legs are given in API 570. They include blanked (blinded) branches, lines with normally closed block valves, lines with one end blanked, pressurised dummy support legs, stagnant control valve bypass piping, spare pump piping, level bridles, pressure relieving device inlet and outlet header piping, pump trim bypass lines, high-point vents, sample points, drains, bleeders, and instrument connections. Dead-legs also include piping that is no longer in use but still connected to the process. Figure 3-1 below shows typical arrangements to be considered when identifying dead-legs. Other illustrations can be found in literature available on-line, such as in the Beacon message February 2022, Centre for Chemical Process Safety, AIChE, Figure 1. Hazard identification of Dead Legs.

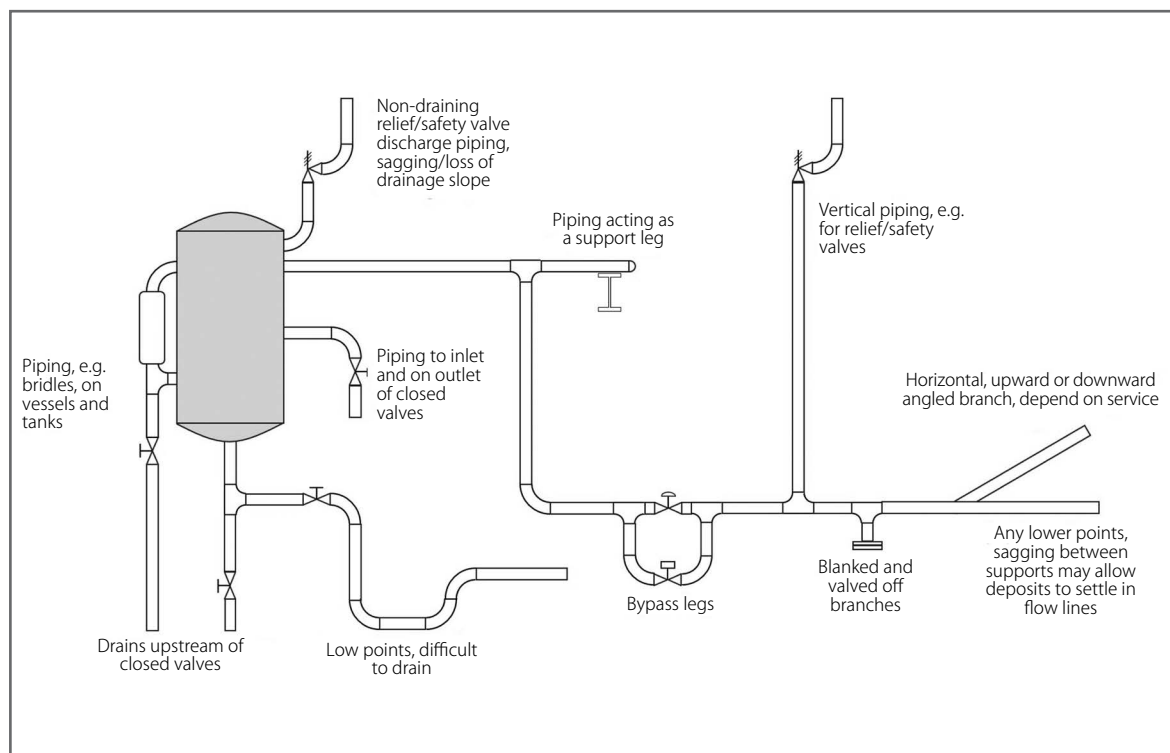


Figure 3-1 Typical piping configurations for dead-leg consideration

Specific examples from within the EEMUA forum included:

- Level bridles and associated equipment;
- Differential pressure piping;
- NRV bypass lines;
- PSV inlet / bypass lines;
- Pressurised dummy leg pipe supports;
- Vessel trim piping (including steam-outs and drains);
- Pressure gauge piping.
- Any drain shown on P&ID with more than one valve;
- Vents and drains;
- Instrument piping (carbon steel);
- All equipment bypass lines;
- Relief lines back to tankage/storage;
- Dead-legs created by demolition;
- Sample point and bleeder piping (including hydrotreater reactor sample points);
- Spare equipment associated pipework;
- Pump casing vents and drains;
- Compressor vents and drains;
- Spare / standby pumps not routinely switched;
- Any piping with the potential for water drop out (sour service line designation);
- All accumulator o/h pump pipework;
- All water boot pump pipework;
- All tank sample lines, tank drains, water drains
- All LPG bullet drain and sample points;
- Intermittent operation piping;
- Injection lines in occasional use
- Operational dead-legs;
- Start up and warm up lines.

The Energy Institute guidance is predominantly aimed at off-shore platforms. API RP 2611 gave more detailed guidance on intermittency and geometric features; API RP 1188 limited detailed guidance to geometry only. However, care needs to be observed as they refer specifically to terminal piping and liquid service, and, for example, rule out all off-top vertical dead-legs. Elements of API RP 2611 and 1188 are raised later in this EEMUA publication.

3.2 Dead-leg categories

Based on the definitions, dead-legs fall into one of two main categories:

- Various described as permanent, static, geometric, mechanical or physical dead-legs – generally blanked or blind ended piping, pressurised dummy support legs, decommissioned and redundant process lines. Many of these originate at plant design and commissioning or may be introduced when modifications are made. They may also be introduced when a section of plant is mothballed. Often they may have no operational purpose.
- Various described as operational, stagnant zone, on/off, intermittent or partial flow dead-legs – these are part of plant operations used intermittently, such as spare pump lines, by-pass lines, control valve by-pass lines, relief valve inlet and outlets, recirculation lines, vents, drains, etc. Often, some operational dead-legs are only used at plant start-up and shut-down or under plant upsets. Leaking valves may also allow partial or low flow in operational dead-legs.

In this guidance the terms permanent and operational are used predominantly for the two categories.

Of the two categories, members agreed that operational dead-legs are more challenging to identify and manage, particularly as operations procedures may change over time and create new operational dead-legs. Equally, delays in completing maintenance, for example replacing a spare pump, may effectively move dead-legs from operational to a permanent category⁽¹³⁾, or, in fact introduce new dead-legs into the systems that were not counted in before.

Operational dead-legs have also been reported to often exhibit greater degradation rates than permanent dead-legs⁽¹⁴⁾.

3.3 Dead-leg degradation

Degradation and corrosion are terms used in this document when considering dead-legs. Whilst degradation is a broader description (that includes all forms of material impairment), corrosion is more commonly used in papers, articles, etc. In this guidance as well as metal loss, corrosion should be thought of in the wider context of degradation.

No flow, low flow and intermittent flow, coupled with the orientation and configuration of dead-legs can make them more susceptible to internal corrosion than the main pipe. For example, API RP 2611 noted that entrained water, when present in hydrocarbons, is typically more corrosive than the hydrocarbons and will tend to phase separate in low flow or stagnant sections. Corrosion can be very localised and the rates can be very severe, often many times that of the main pipe. API RP 1188 draws attention to the threat from freezing of trapped water (whether from separation as above or from hydrostatic test, for example).

The reasons for dead-leg vulnerability include (Table 3-2):

Table 3-2 Features of Dead-legs that can promote degradation

Reason for degradation	Comment
Deposition and accumulation of solid materials, concentration of corrosive species (e.g. ammonium salts, organic acids, hydrogen sulphide and acidic deposits)	Low point, usually connected to main below horizontal.
Collection of (contaminated) water	Low point, connected to main below horizontal (corrosive contaminants, dissolved gasses such as H_2S , CO_2 , SO_2 , O_2 , etc). Loss of drainage slope, line sagging. Degradation and freezing potential in water traps.
Exposure to corrosive dissolved gasses such as, CO_2 , H_2S , O_2	Intermittent flow, leakage flows may renew contact with previously exhausted corrosion species.
Condensation of gaseous components, dew points	Phase change as temperature falls away from main can concentrate contaminants at the condensation point, upward vertical, and connected to hot main above horizontal. Condensing liquids can sometimes lead to stripping of passive protective layers. Condensate in a vertical dead-leg leading to thermal fatigue on run-back down into the main pipework. Process dead-legs to flare systems (non-condensable vents) accumulate liquids.
Process parameters differ from the main	Typically, temperature and flow disturbance reduce away from a hot main which may enhance certain degradation mechanisms not relevant to the main (e.g. temperature drop bringing about possibility of chloride stress corrosion cracking or CUI). Temperatures can fall away quite quickly from the main e.g. systems with relatively low thermal conductivity (such as stainless steel) in low molecular weight gasses duty).
Thermal syphoning, convection currents	Convey warm/hot solids/liquids concentrations to different parts of a dead-leg at different temperatures, e.g. to high points.
Fluid/solid interfaces, deposition at salting temperatures Liquid/gas/vapour interfaces in vertical dead-legs, spare pumps not drained	As temperatures fall away from hot main. Potential concentration of corrosive species.
Turbulence effects from the opening in main	Higher fluid velocities at the entry to the dead-leg and, locally, downstream in the main.

Forum members discussed the factors that can drive degradation of dead-legs – usually internal corrosion – which included: geometry (diameter, length, orientation), materials, constituents, temperatures, flow rates. In particular, flow rate and geometry would have a large influence on whether the dead-leg is “swept clean” of deposits or, for instance, accumulates solid deposits, contaminants, separate liquid fractions or constituents. These are discussed later.

Dead-legs can also be exposed to external degradation, for example, there may be a higher likelihood of Corrosion Under Insulation (CUI) if lagging/cladding defects allow water ingress to the pipe surface and temperature profiles (e.g. dropping away from the main) are adverse for CUI.

3.4 Typical dead-leg degradation mechanisms

The features described in Table 3-2 influence the modes of degradation which can be common to, but also different to, those affecting the main pipe. For example:

- In water contaminated liquid and gas lines, where the dead-leg creates a low point (off bottom of main, is branched or has a trap feature), then water may collect leading to aqueous type corrosion. Contamination of the water or absorption of gases (e.g. H_2S , SO_2) enhance corrosion rates.
- The absence of fluid flow in systems containing microbes (e.g. oil systems, aqueous systems) may allow biofilms to establish and increase the susceptibility to Microbiologically Influenced Corrosion (MIC). For operational dead-legs, intermittent flow may replenish microbial nutrients along with increases in temperature which may enhance established MIC.
- Deposition of solids may increase the susceptibility to Under Deposit Corrosion (UDC). Such deposits can be quite localised.
- Should a large amount of water accumulate and freeze, e.g. in winter weather, it may plug and split the dead-leg (e.g. pipe, bend, valve) due to the constrained volumetric expansion, leading to leakage when thawed out ⁽¹⁵⁾⁽¹⁶⁾. Above ground drain lines may be particularly prone. Winterisation programmes (including insulation checks, heat tracing, purge, dry-out as appropriate) can address these risks.

3.5 Main pipe and attached dead-leg degradation mechanisms

As discussed above there may be quite different types and rates of degradation between the main pipe and the dead-legs which are connected to it. There may also be different degradation and rates between the various types and configurations of dead-legs connected to the same main pipe. Members of the forum discussed the importance of differentiating all dead-legs individually within main corrosion loops and assessing them separately (see also Section 8 on Risk Based Inspection).

It was recognised that where management was by inspection, the inspection coverage (scale, extent and amount) needed to be designed to locate the worst degradation and allow a meaningful inspection in such a way that an effective evaluation could be made.