

Guide to the Management of Pressure Equipment Defined-life Repairs

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Engineering Equipment and Materials Users Association

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Contents

Acknowledgements.....	VIII
Scope and Purpose	IX
Abbreviations / Acronyms used in this Guide.....	X
Definitions.....	XI
Repair Lifecycle and Flowchart.....	XII
1. Damage Assessment	1
1.1 Damage Indication During Operation/Examination	1
1.2 Suitability for Continuation of Service Risk Assessment	1
1.3 Identify Possible Mitigation Actions.....	2
1.4 Damage Assessment and Root Cause	2
1.5 Accuracy and Level of Confidence in the Inspection Data	3
1.6 Engineering Assessment	4
2. Selection of Repair Technique	5
2.1 Assessing Repair Techniques	5
2.1.1 Parent Material	5
2.1.2 Location.....	6
2.1.3 Configuration	6
2.1.4 Operating and Design Conditions	6
2.1.5 Nature and Extent of Anomaly.....	6
2.1.6 History of Defects and Repairs	7
2.1.7 Inherent Risk in Performing Repairs	7
2.1.8 Availability of Repair Material and Personnel.....	7
2.1.9 Limitation on Future Inspection Requirements	8
2.2 Design of Repair.....	8
2.3 Technical Readiness.....	9
2.4 Design Review and Approval of the Repair	9
3. Repair Risk Assessment.....	11
3.1 General.....	11
3.2 Installation Risks.....	11
3.3 Testing Considerations	13
3.4 Risks Endorsement	13

4. Repair Method Statement	14
4.1 Introduction	14
4.2 General.....	14
4.3 Pre-Installation Requirements	14
4.4 Repair Installation Process	15
4.5 Inspection and Test Plan.....	16
4.6 Post installation Requirements	16
5. Carry Out the Repair.....	18
5.1 Installation of Repair.....	18
5.2 Defined-life Repair Register.....	18
5.3 Documentation.....	19
5.3.1 During Repairs	19
5.3.2 Post-Repair.....	19
6. Ongoing Integrity Management and Periodic Examination	20
6.1 General.....	20
6.2 Initial Examination and Benchmarking.....	20
6.3 Periodic Examination	20
6.3.1 Bolted Enclosures.....	21
6.4 Maintenance.....	21
6.4.1 Dual Seal Enclosures	21
6.4.2 Injected Enclosures.....	21
6.5 Extension of Planned Removal Date.....	22
6.6 Deferral / Extension Process	22
6.6.1 Inputs into the Assessment.....	22
6.6.2 Risk Based Assessment	23
6.7 Deferral Justified.....	23
6.8 Deferral Rejected.....	24
7. Repair Removal or Acceptance as Permanent.....	25
7.1 Introduction	25
7.2 Defined-life Repair Removed	25
7.3 Defined-life Repair Acceptance as Permanent	26
8. Quality Assurance.....	27
8.1 General.....	27
8.2 Internal Process Review.....	27
8.3 Key Performance Indicators (KPIs)	28
Appendix A – Repair Types	29
A1 – Mechanical Clamp Repair.....	29
A2 – Composite Repairs	36
A3 – Welded Sleeve / Patch	47
A4 – Repairs to Bolted Joints	48

A5 – Repairs to Valve Packing Leaks.....	56
A6 – Miscellaneous Repairs (Pipe Crimping / Line Kills / Freeze Plugs / Mechanical Connectors / Cold applied composites / Weld Buildup, Weld Overlay and Clad Restoration)	63

Appendix B – Non-Destructive Examination Techniques for Different Repair Types..... 81

References..... 82

EEMUA Publication: Feedback Form 84

EEMUA Publications Catalogue 85

Figures

Figure A1-1	Typical Engineered Repair Clamp with Elastomeric Seal	29
Figure A2-1	Example of a Composite Repair to a Large Component.....	36
Figure A2-2	Example of an External Composite Repair to a Pipe.....	36
Figure A3-1	Epoxy Injection of a Type A Welded Repair Sleeve on a Pipeline	41
Figure A4-1	Examples of Mechanical Clamps	48
Figure A5-1	Valve Packing Repair Example.....	56
Figure A6-1	Pipe Crimp	64
Figure A6-2	Nitrogen Freeze Plug Assembly	66
Figure A6-3	Tapered Locking System Connector.....	67
Figure A6-4	Grooved Flange Connector	69
Figure A6-5	Elastic Strain Preload Connector Fittings	70

Tables

	Terminology used in this Publication.....	XI
Table 8-1	Defined-life Repair Performance Chart Example	27

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Scope and Purpose

In the event of an actionable inspection finding, an in-service leak or in-service damage, the Users typically must decide on whether to install a defined life repair or shutdown and install a permanent repair.

The purpose of this EEMUA publication is to provide an overview with respect to the life cycle management of defined-life repairs. This document will provide guidance for Users to consider when deciding if it is safer to shutdown and perform a permanent repair as well as providing key points to consider when selecting a defined-life repair, assessing the risks and when developing their maintenance, inspection, and replacement strategies post installation.

The primary function of a defined-life repair is to allow the system to return to or remain in service with limited interruption to production until a planned permanent repair can be installed. Although there is industry guidance available on the selection of defined-life repairs (e.g. ASME PCC-2, ISO 24817 and EI composite repair guidance), at the time of publication there was limited known industry guidance covering the life cycle management of defined-life repairs, e.g.

- How long can a defined-life repair remain in service?
- How to extend the life of a defined-life repair?
- How to make a defined-life repair permanent?

This document was developed by Engineers who work in the Power Generation, Chemical Production, and Oil and Gas Sectors. Although the use of this document was originally targeted for static equipment, it is recognised that it may be applicable to a range of other industries – Shipping, Mining, Steel, Nuclear, Water and Food & Beverages to name a few. It is the responsibility of the User to ensure specific details relating to their industry are considered when applying the guidance from this document.

Each Company's organisational structure will vary in terms of maintenance, engineering, and inspection departments. As such, it is the responsibility of the User or Equipment Owner to determine the strategy for defined-life repairs within their organisation. The strategy should be endorsed by the relevant Technical Authority for the Company.

This publication advises that a risk-based approach is adopted to allow flexibility in application of defined-life repairs to the relevant situations, to ensure correct prioritisation based on the overall repair life cycle, and to ensure that the selected defined-life repair does not adversely affect the safe operation of the system.

It is expected that the reader has a basic competency in static equipment design and as such the level of detail contained within this guidance document has been set appropriately.

Abbreviations/Acronyms used in this Guide

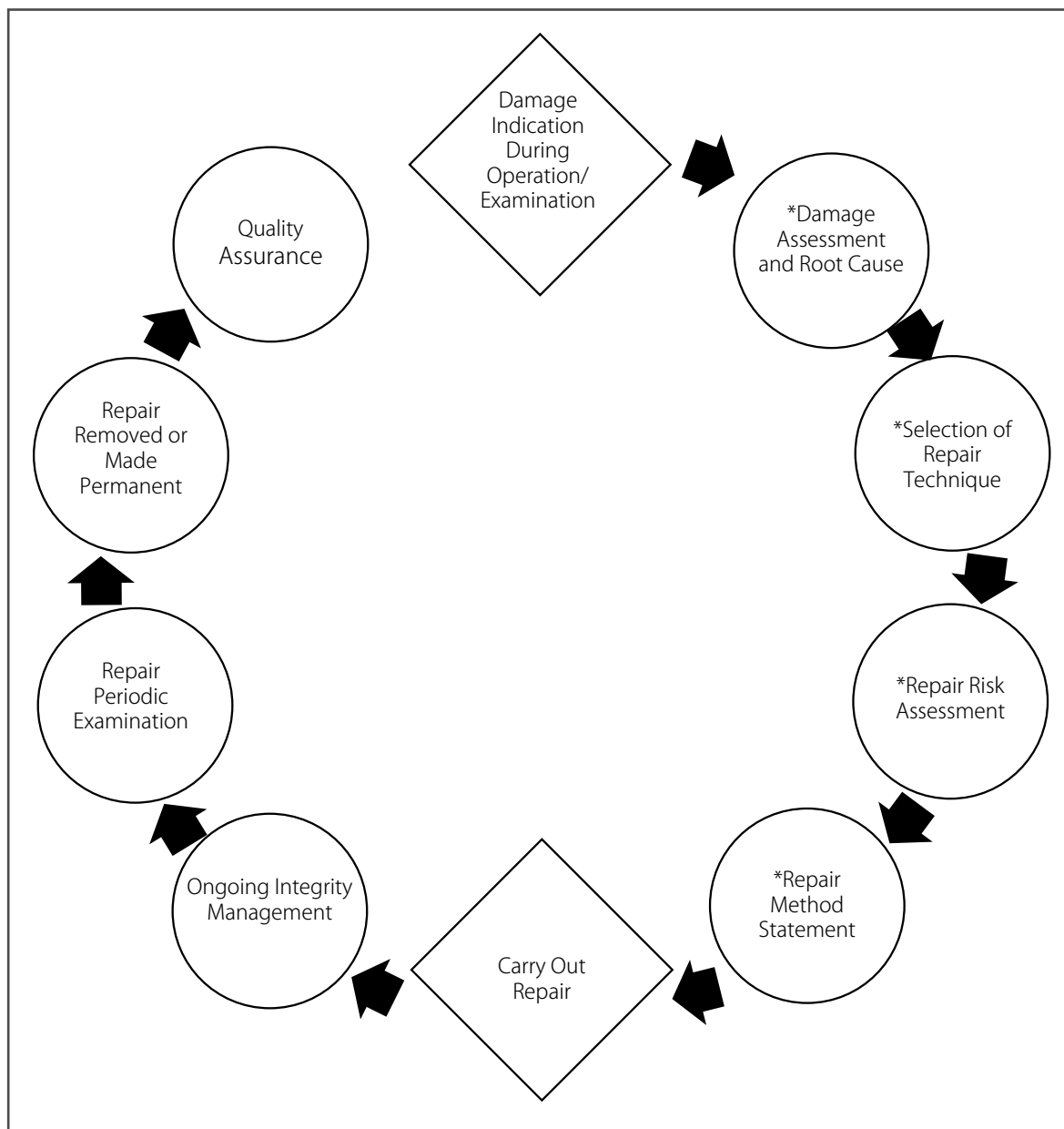
ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
DLR	Defined-Life Repair
ECA	Engineering Criticality Assessment
EEMUA	Engineering Equipment and Materials Users Association
FFS	Fitness-For-Service
GA	General Arrangement
ITP	Inspection and Test Plan
LOPC	Loss of Primary Containment
MOC	Management of Change
NDT	Non-Destructive Testing
OEM	Original Equipment Manufacturer
P&ID	Process & Instrumentation Diagram
PMI	Positive Material Identification
PPE	Personal Protective Equipment
PSSR	Pressure Systems Safety Regulations 2000
QA	Quality Assurance
QC	Quality Control
RCFA	Root Cause Failure Analysis
RT	Radiographic Testing
SCC	Stress Corrosion Cracking
TAR	Turnaround
UT	Ultrasonic Testing
WPQR	Weld Procedure Qualification Record
WPS	Weld Procedure

Definitions

Table Terminology used in this Publication

Anomaly	Something that has been identified that is actually or potentially detrimental to the integrity of the equipment. Examples are excessive corrosion, cracks or unexpected loss of primary containment
Defined-life Repair	Repairs that restore integrity to continue safe operation until permanent repairs can be scheduled and accomplished within a period acceptable to the technical authority. A defined-life repair should be removed and replaced with a suitable permanent repair or reinstated to original design intent at the next available opportunity. A defined-life repair may remain in place for a longer period only if approved and documented by a technical authority. A "defined-life repair" is commonly referred to in industry as a "temporary repair".
Permanent Repair	Repairs that restore an item to a condition that is demonstrated as fit for service for its remaining design life or defined service life (through to cessation of production) If any repair changes the design temperature or design pressure, the requirements for re-rating shall be satisfied approved and documented. A repair can be the addition or replacement of pressure or non-pressure parts that do not change the rating of the item.
Technical Authority	Position within the User's organisation who has responsibility for the assurance and technical suitability of equipment within their discipline. Utilise the organisation MOC procedure to define who does the work and who approves it. All tasks should be completed by suitably qualified and experienced persons. For pressure bearing equipment with relevant fluid to the PSSR's then the technical authority should be the appointed competent person.
User	The organization which uses the equipment and has responsibilities under the Provision and Use of Work Equipment Regulations 1998.
Static Equipment	Non-moving equipment such as pressure vessels (equipment), heat exchangers, piping, storage tanks (including atmospheric), valves, pressure relieving devices, boilers, furnaces/heaters, and structures. Also includes the repair of casings for rotating equipment.
Pressure Equipment	Vessels, piping, safety accessories and pressure accessories, including, where applicable, elements attached to pressurised parts, such as flanges, nozzles, couplings, supports, lifting lugs

Repair Lifecycle and Flowchart



* At each of these stages, the risk of pursuing the defined life repair must be considered against the safer option of shutting down and performing a permanent replacement

1 Damage Assessment

1.1 Damage Indication During Operation/Examination

Loss of containment in static equipment can occur in many ways. Failures and potential failures can be attributed to a variety of damage mechanisms, some common mechanisms include:

- Internal or external corrosion of the containment wall.
- Leaks from flanged or threaded connections.
- Material loss caused by erosion, fretting/chafing or gouging mechanisms.
- Cracking initiated through creep, fatigue, or stress corrosion cracking mechanisms.
- Mechanical or impact damage (dents, scratches, gouging, scouring, distortion) typically caused by maintenance, third-party activities, or terrain settlement.

Note: This list is not exhaustive; the full range of potential damage mechanisms can be very long.

Anomalies may be identified during a planned inspection (on or offline), or it may be identified through operational observations when the equipment is in service due to changes in physical or operating conditions (leaks, vibrations, operational step changes). Upon discovery of such an anomaly it is essential that steps are taken as soon as possible to assess the damage and take appropriate action to minimise risk.

1.2 Suitability for Continuation of Service Risk Assessment

When an anomaly is discovered on equipment in service, in the event that it is considered at risk of imminent failure, the priorities shall be to report to the regulatory bodies where required (e.g UK PSSR reporting under regulation 10 – “imminent Danger”) and remove the equipment from service until it can be repaired. For all other anomalies a risk assessment should be completed promptly to determine if it is safe for the equipment to remain in service. The urgency of this assessment should be governed by the risk presented by the anomaly and it should consider potential safety (of site personnel and the public), health and environmental consequences, and business commercial, regulatory and reputational impact that could result from a loss of primary containment. The intent of the assessment shall be to keep the risk tolerable (in accordance with the operator’s risk acceptance criteria) and as low as reasonably practicable (ALARP) while complying with local regulation.

The default action should be that the equipment is de-pressurised and made safe while it is evaluated by competent inspection and engineering personnel. However, three considerations that may support a different approach are when:

- initiating shutdown procedures could result in more onerous transient operating conditions or loads at the location of the defect, which may initiate or worsen a failure.
- the wider-scale risk of shutting down and restarting plant to allow offline repair may be disproportionate to the risk of continued operation.
- the business cost due to unavailability when shutting down the equipment for offline repair is grossly disproportionate to the risk of continued operation.

Having considered these factors alongside the engineering judgement of the failure, its potential for further deterioration / escalation and all risks involved in performing the necessary inspection to fully quantify the anomaly, a decision can be made on whether it is safe to remain online.

It is important that Users have established procedures in place which set out the assessment process, the roles and responsibilities of personnel and how the initial assessment will be documented and shared with relevant parties. The procedures should also recognise that the discovery of anomalies can happen at any time during operations and are not restricted to normal working hours.

1.3 Identify Possible Mitigation Actions

Following the risk assessment described in Section 1.2, the mitigating actions required to ensure that the risk remains ALARP should be identified and executed. These may include, but are not limited to:

- Reducing the operating pressures and/or temperatures to reduce loads on the equipment, which may reduce deterioration rates and lessen potential consequences.
- Increasing the surveillance of the defected area, whilst being conscious of the danger of putting people at risk. If it is deemed appropriate, careful task risk assessments and additional personal protective equipment (PPE) may be warranted.
- Minimising the likelihood of exposing personnel to danger (e.g., barrier off the area; erect warning signs; inform workers, managers, and permit issuing authorities; cancel work in the area or include new risks in task assessments).
- Installing a short-term running repair (stop gap repair). These are typically non engineered solutions intended for very short durations until the plant can be safely shutdown (e.g. wooden plugs, rubber patches banded in place). When attempting such repairs, the potential for escalation must be considered and a task risk assessment carried out before attempting such a repair. These types of repairs are unlikely to be endorsed by regulator bodies and should only be considered for non-hazardous fluids.
- Fitting of a short term emergency repair bandage or strap (non-engineered repairs). These can mitigate immediate consequences but may complicate future engineered repairs or could in some cases cause escalation (e.g., fitting a clamp may cause collapse of thin pipework).
- For short term running repairs and emergency bandages / straps, these types of repairs are unlikely to be endorsed by regulator bodies and should only be considered for non-hazardous fluids.

1.4 Damage Assessment and Root Cause

Whether the equipment remains in service or it has been shut down, the next stage shall be to characterise the damage in terms of severity and extent, and to determine the root cause of the damage. Lessons learnt from the Root Cause Failure Analysis (RCFA) should be fed back into the USERs integrity management systems to allow them to update their inspection and maintenance processes to prevent similar incidents occurring in the future.

A likely starting point for the damage assessment and root cause analysis may be the application of various inspection and non-destructive testing (NDT) techniques as determined by a competent person. However, there may be limitations on techniques that can be applied if the equipment remains in service (e.g. due to high temperature).

The intent of the inspection and/or testing shall be to characterise the damage in sufficient detail to allow an engineering assessment of the safety of continued operation, or to assess potential

repair options. The axial extent, circumferential extent, and depth of the damage should be measured. If the anomaly is a dent, the depth and extent of the dent should be known. Likewise, if the defect is a bulge, the height and extent of the bulge should be known. If the defect is a wrinkle, its depth, height, length, and extent should be known. When any of these parameters are unknown or cannot be readily determined it is advisable to make worst-case, conservative assumptions before proposing for the fitness-for-service (FFS) assessment or an engineering critical assessment (ECA). These types of assessments can be performed to show that an anomaly does not seriously degrade the serviceability and safety of the equipment. If the nature and extent of the damage is such that it does not adversely affect pressure equipment integrity over its remaining life, it is usually preferable not to make any defined-life repair. However, it is recommended that these assumptions are revisited and verified at fixed intervals to ensure that they were correct at the time of assessment.

For equipment remaining in service, consideration must be given to the risks of in-service inspection with a known failure/anomaly in place. For example, some risks to be considered when assessing a leak behind insulation are given below:

- What are the process conditions, and the resulting potential consequences (e.g. composition, pressure, temperature)?
- Could removing the insulation lead to escalation due to the disturbance of corrosion product that may be providing some containment?
- Could hazardous process fluids (flammable, toxic, cryogenic, steam etc.) be present in the vicinity? For example, hydrocarbons present in the insulation which could ignite if above autoignition or form a flammable gas cloud.
- Could removing insulation lead to a higher leakage rate of hazardous process fluids?
- Could the leak source be from a crack, and what is the likelihood of the crack becoming unstable and failing catastrophically?
- Could invisible plumes of hot gas or steam be present which could injure personnel?

Once the extent of the damage has been characterized an assessment shall be undertaken to identify the damage mechanism and where applicable, what had changed to allow the damage to occur. This should provide an indication of the risk of continued degradation and may also prompt for further targeted inspection to determine if the same problem might exist in other similar locations. Where it may not have been possible to determine the probable root cause, great care should be taken in progressing any type of defined-life repair as it may not be possible to safely predict the future degradation risk.

1.5 Accuracy and Level of Confidence in the Inspection Data

It is important that integrity management decisions are made on accurate and reliable data. During the damage assessment and root cause it is important that responsible personnel are aware of the source of the inspection data and have sufficient confidence in its accuracy and validity. Inspection data should be provided with an indication of its realistic measurement tolerance, the tolerance can vary significantly based on inspection technique used.

Depending on the degradation mechanisms involved, the engineer should also be prepared to challenge the scope of inspection performed (e.g. a single orientation RT shot may not have identified the worst case of wall loss). If there are concerns that there may be other areas of damage, the inspection scope should be extended accordingly and considered in the damage assessment.

1.6 Engineering Assessment

The information obtained from the damage assessment shall be used to complete an engineering assessment of the current and future state of the equipment to determine if it is safe to remain in service, and for how long.

Fitness for service codes such as API 579, BS 7910, ASME B31G can be used to assist the engineering assessment. Typically, assessments should be performed against original design conditions. However, it may be appropriate to de-rate the maximum operating limits to demonstrate fitness for service, provided that there is confidence that the less onerous limits can be maintained and reliably monitored. Any alterations or modifications to the equipment and/or operating limits shall be conducted under approved management of change procedures. During the assessment it may become apparent that more data is required, and therefore additional inspection or non-destructive testing could be required. Where complete data sets cannot be readily acquired, conservative assumptions based on available data may be necessary. All assumptions must be clearly documented.

The conclusions of the engineering assessment should be used to determine the most appropriate action out of the following:

- The equipment is fit for service and the damage mechanism has been arrested. Therefore, it can remain in-service indefinitely, though monitoring for further deterioration will normally be required.
- The equipment is fit for service, but the damage is expected to worsen. If the projected life is sufficient to reach the next opportunity for offline repair (e.g. next planned shutdown) then a repair might not be necessary but monitoring for further deterioration will normally be required. Alternatively, an engineered repair may need to be considered to ensure it is safe for the item to remain in service for the required duration.
- The equipment is not fit for service and options for offline and online repair or replacement should be considered, taking into account the risk of continuing to operate the equipment in the current condition.

2 Selection of Repair Technique

2.1 Assessing Repair Techniques

When assessing the suitability of defined-life repair techniques several important factors must be considered. This section covers the key details for the main factors that are listed below:

- Parent material
- Location
- Configuration
- Operating and design characteristics
- Nature and extent of anomaly
- History of defects and repairs
- Inherent risk of performing repairs
- Availability of resource and personnel
- Limitations on future inspection requirements

The greater the understanding of these main factors, the greater the confidence in determining the correct course of action (i.e. defined-life repair vs off-line replacement, and conditional operating parameters).

2.1.1 Parent Material

Knowledge and understanding of material properties are essential when assessing the suitability of materials used in defined-life repairs. The chemical and mechanical properties of materials must be known to ensure compatibility with the existing parent material of the equipment requiring repair and the process fluids. Material compatibility is only relevant where the defined-life repair is in contact with the surface medium. All materials used in defined-life repairs are to be fully traceable and come with a level of quality assurance that ensures that final material properties are within specification. This can be achieved via quality assurance documentation which should be reviewed by competent personnel. Some common topics are listed below:

- Melting procedures
- Testing procedures
- Material origin
- Heat treatment
- Material manufacturing route
- Process fluid composition (MSDS)
- Mill certificates
- Hardness tests
- Chemical tests
- Spark Test

In cases where there is a lack of information regarding the parent material of the equipment requiring repair (old equipment with limited design information) then positive material

identification (PMI) should be used to verify chemical composition. Furthermore, if there is no documented evidence to confirm the material properties then a material analysis and testing laboratory accredited to ISO 17025 should be consulted to evaluate material quality.

2.1.2 Location

The location of the equipment may influence the selection of defined-life repair. Some factors to consider regarding location include, but are not limited to:

- Accessibility for inspector to examine equipment or technician to implement a repair (e.g. accessibility for tools).
- Dimensions of repair and available space (e.g., length and thickness, clamp vs wrap, off-shelf solution or bespoke).
- Proximity to hazardous, toxic and flammable zones.
- Proximity to populated or environmentally sensitive areas.
- Considerations for aboveground versus belowground (soil conditions, moisture, etc).

2.1.3 Configuration

The configuration of the equipment will influence the most suitable technique for a defined-life repair. Therefore, a review into the damage mechanism and configuration of the equipment must be completed. This may include reviewing inspection reports, piping isometrics, GA drawings, mechanical datasheets, manufacturing data books, or other documents to assess the suitability of a defined-life repair technique against the configuration and specific location of the damage within the equipment.

The choice of repair technique will often require special consideration to address issues such as cracking near existing welds, thermal growth restriction, additional weight / loading, resulting in excessive stresses.

2.1.4 Operating and Design Conditions

The original and future design and operating conditions (i.e., min/max pressure and temperature) of the equipment along with any excursions must be known and the suitability of any installed protective devices should be verified. Additionally, the discrete point pressures and temperatures at the location of the repair and if the repair is to be installed in the “hot” or “cold” position should also be known. Other conditions that could affect a repair decision such as cyclical loading, induced vibration, credible upset conditions, type of product, and its flow velocity etc. should be determined. The greater the understanding of these conditions the greater the confidence there will be in the selection of a suitable defined-life repair technique.

2.1.5 Nature and Extent of Anomaly

When selecting suitable repair techniques, the nature and extent of anomalies must be understood. Anomalies may arise during the design or manufacturing stage through faulty design, poor workmanship, inadequate materials of construction, incorrect welding techniques, or weld misalignment. Failures that are attribute to these types of anomalies usually occur in an early service period. Failures that occur in normal service can usually be attributed to in-service anomalies such as corrosion, pitting corrosion, wall thinning, changes in the working parameters, operation of the vessel outside of design limits, impurities in the operating fluids, metallurgical changes in the base metal, and mechanical damage such as cracks, grooves, gouges, dents, bulges, pinholes, laminations, and blisters etc.

The findings from the damage assessment and root cause analysis (Section 1.4) shall be used to make an informed decision regarding the most suitable repair technique, considering the nature and extent of all anomalies against the capabilities of the repair technique chosen. Ideally, the repair technique selected should arrest the underlying damage mechanism, and if not, it should either permit inspection or accommodate future damage progression at the end of the defined life of the repair.

2.1.6 History of Defects and Repairs

The Technical Authority should carefully review all previous examination reports and repair history to identify:

- Any historic damage mechanisms including their similarities and/or dissimilarities.
- The type of repair performed at the time along with the scrutiny of the repair Inspection & Test Plans (ITP) and Quality Assurance (QA) packs.
- Any deviations in design or operation parameters.
- MOC history for the equipment/system.
- The information gathered through the history of defects and repairs is vital when applying the guidance from this publication.

2.1.7 Inherent Risk in Performing Repairs

The Technical Authority should consider the inherent risk involved when performing a defined-life repair. This includes both the likelihood and consequence of a hazard occurring during the repair process. Typically, the likelihood of a hazard occurring increases as the complexity of the repair procedure increases. For example, applying a mechanical bolted clamp or composite sleeve is usually less complex than applying a pressure-containment sleeve since they do not require welding. The immediate consequence of making a mistake in the repair procedure is also important. For example, excessive grinding or improper welding may have a higher consequence than improper application of a composite sleeve.

Additional risks to consider include risks associated with access restrictions and working at height, and risks in planning phase of the repair includes TAR scheduling, planned outages, shutdown opportunities, seasonal variations, and typical variations in weather conditions.

Refer to section 3 for more details of the repair risk assessment.

2.1.8 Availability of Repair Material and Personnel

Availability of repair material and competent personnel are especially important when repairs need to be made quickly. Some factors to consider include:

- What resources are available to implement the repair?
- Are repair materials stocked, or do they have to be obtained from a vendor?
- What are the lead times for repair material and/or competent personnel?
- What is the timeline for implementing the repair?
- If a third-party repair company is used, what are their capabilities and how do you ensure they are competent?
- Vendor guarantees for selected material.

2.1.9 Limitation on Future Inspection Requirements

To monitor on going integrity of repair it is necessary to identify all those factors which can potentially affect the periodic examination of defined-life repairs. These factors can significantly impact the life of defined-life repairs. For example, human or inspection equipment access to repair, operational parameters etc.

2.2 Design of Repair

The selected defined-life repair type should satisfy the above factors as far as reasonably practicable, and its design must detail all physical and technical requirements. This would typically be conveyed via drawing(s), a datasheet and / or a step by step written description. A repair installation form should also be created, detailing all of the parameters considered.

The design of the repair should clearly address the following key parameters:

- The type of repair(s) to be used.
- The physical location(s) of the repair.
- The assumed size of defect (including any allowances for continued growth during its defined life).
- The limits of the area(s) to be repaired.
- A review of operating and design conditions (in particular, temperature and pressure, cyclic loading) to ensure adequate sealing.
- Details of any enabling works required to perform the repairs. For example:
 - Location and type of any temporary supports.
 - Surface preparation requirements and extent (this varies between repair techniques and can be critical to the repair success).
 - Any machining / grinding requirements (e.g. weld cap removal).
 - Repair access requirements (e.g. scaffolding).
 - Requirement for any habitats (simple shelters to zone rated and pressurized).
 - Site access / logistics review to identify how material and equipment can be transported to and from the site.
 - Identification of zoning / barrier requirements to limit access to the repair site, without restricting access to other key parts of the operating plant.
 - Any plant operating restrictions to be implemented before, during and /or after the repair.
- Details of any special tools or auxiliaries.
- Material compatibility
- Materials parts list and spare parts (to be verified prior to starting work).
- Consumables lists.
- Specific installation considerations. For example:
 - Lifting requirements.
 - Confined space entry.
 - Physical isolations.
 - Elevated work.
 - Electrical earthing requirements.
 - Site specific personal protective equipment (PPE).
 - Training and inductions.
- Qualification requirements of key personnel.
- Design calculations.
- Defined life of repair and removal date
- Testing of repair
- Any other relevant information.

The responsibility for developing document(s) will depend on the type of repair being installed. Often supporting documents will be provided by the specialist third-party (e.g. custom-made external clamps or composite repairs). However, the plant owner will ultimately be responsible for approving the document. The design may also be subject to third party or regulatory review and approval.

The only exception to the above, would be if the decision is to install a short-term running repair (stop gap repair). These are typically non engineered solutions intended for very short durations until the plant can be safely shutdown (e.g. wooden plugs, rubber patches banded in place). These types of intervention would only be recommended for non-hazardous services and a task risk assessment must be carried out before attempting such a repair. Refer to section 1.3 for more details.

2.3 Technical Readiness

Where “off the shelf” or proprietary solutions are being considered for a defined-life repair, it is not uncommon to find that the solution being considered may not have been qualified for applications that exactly match the problem at hand. This is commonly referred to as the “technology readiness” of the solution.

Prior to using a solution outside of technology readiness, a documented engineering review should be undertaken to assess the risk of extrapolating the existing design (e.g. material and fluid compatibility, changes to temperature and pressure limits, etc.) and should be subject to approval by the technical authority. Caution would be recommended in applying this approach for safety critical applications where a more detailed engineering assessment should be undertaken unless the extrapolation can be demonstrated to have minimal risk.

To support the decision process, consider the use of tools such as;

- Design by analysis.
- Performing a mock up test / factory acceptance test.
- In service testing where the risk of LOPC can be justified.

The justification for using a solution outside of its qualified range shall be included in the overall Risk Endorsement (Section 3.4).

2.4 Design Review and Approval of the Repair

The design of the defined-life repair must be sufficiently scrutinised by a team of competent individuals. The review team should be multi-disciplinary, including expertise from mechanical, process, process safety, operations, integrity, and any other disciplines when required. The review should be completed in-line with the Management of Change (MOC) processes and procedures for the site. The MOC will typically include, but may not be limited to:

- Review of original design specifications and repair design specifications.
- Review of any existing repairs on the same line / system and to assess the corresponding cumulative / compound risk of multiple repairs on a system (potentially at close proximity).
- Associated technical documentation.
- Assessment into the limitations and conditions associated with the repair e.g. assessment by the leak sealing contractor of any practical constraints to achieving a proper seal, such as pipe ovality.
- Requirements for specialist technical approval e.g. Inspector, Metallurgist, Civil, EC&I Engineer.

- Calculations to support the repair design. These should:
 - Demonstrate that the repair is in accordance with a recognised standard e.g. ASME VIII (fabricated clamp), ASME PCC 2– Section 4.1, ISO 24817 (Composite wraps).
 - Demonstrate that the design provides sufficient strength to resist the normal radial and axial load due to internal pressure, and other forces e.g. thermal expansion.
 - Address whether or not additional restraints are required to prevent the pipe escaping from the repair in event of total failure, e.g. Differential force due to an enclosure fitted over a reducer.
 - Address whether or not additional structural restraints are necessary, (e.g. due to additional stresses imposed on linework or equipment as a result of the repair arrangement), e.g. self-load/bending moment.
 - Demonstrate that all other relevant aspects of the system being repaired have been considered.
 - Support the defined-life limit of the repair
- Chemical compatibility of all credible process fluids with any repair component that is, or could be, fluid facing.
- In the case of compound-injection leak sealing, a review into the compatibility of the chosen injection compound with the process conditions and the materials of construction.
- Consideration of the potential failure modes if the process fluid promotes stress corrosion cracking (SCC) mechanisms. e.g. encapsulation of a flange and bolting in SCC services such as caustic.
- Consideration of any fireproofing requirements.
- Confirmation that the repair has been physically marked in the field, and arrangements have been made to inspect the repair within the specified period.
- Confirmation that additional mitigation measures have been applied where practical, eg.. protective barriers have been installed to avoid impact damage.

The Technical Authority should also consider the influence of a repair on maintaining the integrity of pressure equipment during future operation. For a defined-life repair, the convenience of performing a future repair, including removal, should be evaluated. The Technical Authority should also determine whether the repair will adversely affect future inspection or testing of pressure equipment. For example, in locations where flexibility is important or where loads such as additional weight other than internal pressure may affect the pressure equipment.

A short-term running repairs (stop gap repairs) often need to be installed quickly to arrest an LOPC or mitigate an emergent integrity threat. These types of repairs should be accessed as a non-engineered solution which provides a qualitative not quantitative reduction in risk. In these instances, an individual task risk assessment must be carried out before attempting such a repair and their time in service should be directly related to the LOPC risks that they are addressing and appropriate monitoring implemented whilst a more permanent solution is identified. Refer to Appendix A for guidance on specific repair types.

3 Repair Risk Assessment

3.1 General

Prior to developing the defined-life repair method statement, a detailed risk assessment should be undertaken to identify all potential installation risks and any practical mitigations that can be implemented. All risks should be identified and mitigations put in place to reduce them to as low as reasonably practicable (ALARP) and in compliance with local regulations as well as company standards. It is the User's responsibility to lead the repair Risk Assessment. The Inspection body/ technical authority can be consulted for technical input, but their independence should be maintained

3.2 Installation Risks

The process of preparing and installing the defined-life repair introduce risks that should be considered in the overall risk management process. Risks that should be considered included when selecting a repair technique include, but are not limited to:

- Positive Identification and confirmation of the repair location. There have been cases where repairs have been installed on the wrong line and the actual defect has continued to deteriorate to failure
- Extent and accuracy of the NDT performed to assess the extent of the defect, the damage mechanism(s) and the rate of future deterioration. For example, Accuracy / Tolerance on the results provided, verification that the defect does not extend upstream or downstream of the areas examined. The risk of the defect escalating before the installation of the repair (e.g. thin spot progressing to a leak, or a weep progressing to a leak)
- Experience and competency of personnel involved in the lifecycle of the defined life repair from identification to permanent repair, including the use of contractors.
- Robustness of the repair technique being proposed. For example, using an off the shelf short term repair to get to a planned shutdown verses a fully engineered repair to last until the next planned TAR.

Space limitations, which may restrict safe handling and installation of the repair.

- Risk of impacts during lifting activities (e.g. lifting over or next to live equipment).
- Personal risks such as pinch points, trapped fingers and burn risks from hot surfaces.

Risk of detrimentally disturbing the defect during the installation of the repair, which could lead to LOPC. For example, during surface preparation to accommodate the repair.

- Prior to performing any surface preparation, the integrity of the section being prepared must be inspected to verify that there is sufficient material thickness remaining to maintain pressure and structural integrity.
- It is not uncommon for the operating company to develop a specific BOLL (blasting on live lines) procedure to control the execution of surface preparation on live lines to reduce the risk of a leak developing during surface preparation.

- Where there are concerns or uncertainty over the integrity of the proposed surface preparation locations, it is often necessary to re-evaluate the extent or design of the repair.

Risk of damaging the equipment or escalating the defect due to the nature of the selected repair technique. These may include:

- Imposed clamping loads.
- The additional weight of repair.
- Hot work (welding, brazing, cutting, grinding, shot blasting) can result in blow through if the material is too thin or the process is not appropriately controlled.
- Increased weight or stiffness damaging associated equipment (e.g. loads on pumps / compressors / vessels), this should have been considered during the design of the repair with additional supports added as necessary.
- Altered natural frequency of the system which could potentially cause service resonance.
- Introduction of hot or cold spots affecting corrosion rates.
- In the case of injection clamps, the effect of the sealant on the equipment should be considered. These may include, but not limited to:
 - External loading due to clamp and sealant. This should be calculated during the design phase.
 - For sealing gasket leaks, the additional loading on the bolting and the potential for changing the pressure end load due by altering the gasket sealing diameter.
 - Improper reinjection. Reinjection intervals and pressures should be agreed with the vendor prior to installation.

Complicated geometry making installation and sealing difficult. The more complicated the geometry the more difficult it usually is to generate an effective seal.

Inadequate support. Temporary supports should be installed if an existing support is taken out of service as part of the repair or the repair increased the weight of the system beyond acceptable limits.

Means of emergency access or egress, considering the physical location of the repair and the layout of the work site during all stages of the installation, i.e. could equipment restrict access or egress? Consider a minimum of 2 independent escape routes.

Actions to be taken in the case of emergency, i.e. documented contingency plans and emergency procedures.

Depending on the immediate and future potential risk are appropriate barriers / signs in place to prevent the defect being disturbed and minimise risk to site personnel.

If there is an active leak, review the health and safety risks associated with working at the leak site? For example, toxicity, flammability, asphyxiants.

Any work required to install the repair should be compatible with the Hazardous area classification of the part of the plant that the defect was found in. If necessary, consider the use of ATEX rated pressurised habitats.

Is there inventory still in the line? Is this with / without pressure? What Isolation options are available in the event of escalation? Are document contingency plans available? (e.g. location of shutdown valves / shutdown buttons / access to operator radio to talk to control room?). Available active firefighting precautions implemented to reduce the risk of escalation in the event of a fire.

Human factors risk such as:

- Completeness and clarity of documented procedures. Is there a risk of deviating from the requirements?
- How has the defect(s) been identified in the field. Is there a risk that an incorrect line will be worked on by mistake?
- If surface preparation is required to facilitate the installation of the defined-life repair, what controls are in place to identify the areas that have been deemed safe worked on?

The additional risks that are specific to the selected defined-life repair method are referenced in Appendix A.

3.3 Testing Considerations

Depending upon the type of repair installed, it may be possible to physically test the integrity of the repair, e.g. pressure testing an enclosure after installation of a sleeve or clamp. Whilst this may be seen as a positive step to provide confidence in the integrity of the repair, the immediate and longer-term risks should be considered. For example, applying a pressure test to an enclosure will introduce external loads on to the equipment, that it would not normally experience in service. Calculations should be undertaken to verify that there is an acceptable margin of safety before collapse. If the operating pressure of the equipment is included as a mitigation in the calculation, checks should be implemented to verify that the operating pressure is maintained during the duration of the pressure test.

If a hydrotest is performed, considerations should be made to the long-term risk any of the hydrotest fluid remaining trapped within the enclosure (e.g. accelerated crevice corrosion).

Refer to EEMUA Publication 168 - A guide to the pressure testing of in-service pressurised equipment for greater detail of the risks of performing pressure test on in service equipment.

3.4 Risks Endorsement

The company's risk assessment procedure should document how the final risk is to be reviewed and endorsed. The process should formally document the findings from the risk assessment with a statement on the decision to proceed with the repair or not, together with any associated conditions that must be met to support that decision. (e.g. portable firefighting equipment to be moved into the area, additional scaffolding to be installed, process engineer on standby, etc). Depending on the final risk level, it is common for the site procedures to have a tiered approval process, e.g. where low level activities can be signed off at a discipline level, whereas the highest risks require sign off by the site manager.

4 Repair Method Statement

4.1 Introduction

Prior to carrying out a repair a method statement should be prepared, reviewed, and approved. A documented repair method statement and its associated Inspection and Test Plan (ITP) will form a key part of a site's control of work process and should be developed to mitigate the risks identified within the risk assessment.

4.2 General

The repair method statement and ITP should provide a comprehensive set of instructions and checks to allow the defined-life repair to be installed. The repair method statement should address the following key points:

1. Pre-installation requirements
2. Repair installation process
3. Post installation requirements
4. Inspection and test plan (ITP)

The repair method statement should be considered as a controlled document and subjected to technical reviews and approvals.

Checklists for issues to consider in the repair method statement is included in Appendix A.

4.3 Pre-Installation Requirements

Pre-installation requirements should be specified within the design method statement to validate any assumptions, preliminary measurements, or estimations made when designing the repair. The pre-installation requirements will depend on the complexity of the repair and/or the time interval between the repair being specified and installed, some common factors to consider include, but are not limited to:

- Additional analysis / Mock up test:
 - Physical testing is not required for every application. However, in circumstances where a new technique is used, or the application is outside the operating boundaries of previous qualifications, a mathematical assessment or analysis should be completed to demonstrate the integrity of the repair and its compliance with a relevant code or standard on a case-by-case basis.
 - If a physical test is found to be justified (typically high-risk applications, where a new contractor is being used, where the repair is at the extremes of existing technology / materials) or where there are likely to be significant challenges in the field (e.g. limited access), a mock-up trial should be conducted. The mock-up trial must replicate similar in-service conditions and its performance should be monitored to determine if the application of the repair is suitable. The qualification process of the repair should also include the appropriate documentation and control.
- Perform positive Identification and confirmation of the repair location(s).

- Additional inspections to verify that the defect has not propagated significantly since the last inspection and are consistent with dimension assumed in the design (limits on defect sizes should be specified as a go / no go check).
- Confirmation that the designed repair is compliant with a specified code (e.g. ISO 24817, ASME PCC 2).
- Detailed dimension surveys to verify the design of the defined-life repair. (Tolerances should be specified as a go / no go check on acceptable installation).
- Site surveys to verify that there is sufficient clearance round the defect to allow the repair to be performed with the equipment available.
- Verification that all equipment to be used has been maintained and where applicable is within its specified calibration interval.
- Inventory checks of all parts and spare parts required before starting.
- Installation / readiness of all enabling works identified during the design of the repair (Section 2.2).
- Competency assessment of all trades by reviewing of training and qualification records of all trades and to confirmation of sufficient experience and competency to perform the work.
- Review of quality assurance documentation for key contractors, suppliers, and sub suppliers.
- Review of contingency plans for all probable scenarios.
- Environmental assessments.
- Completion of permits and other safe system of work documentation (Risk assessments, method statements, supporting certificates etc.).
- Local authority's notification and involvement (where applicable).
- The outcome from the pre-installation requirements review should include a go / no go decision to perform the repair.

4.4 Repair Installation Process

The design method statement should include a comprehensive section covering the repair installation process. It is expected that some of these steps would be automatically covered by the site's permit to work system. Some factors to be considered include but are not limited to:

- Appointed Site responsible engineer(s) for the repair (multiple site representatives may need to be assigned if the repair will extend over multiple shifts).
- Schedule of works.
- Requirements for permits and other safe system of work documentation.
- Repair manufacturer/designer instructions and requirements.
- The type of habitat (if any) required (E.g. wind / dust shielding to ATEX certified pressurised enclosures).
- Toolbox talks.
- Personal risk awareness and "Stop the Job" obligations.
- Communication of contingency plans and emergency contact details.
- A detailed repair installation sequence, with clear roles and responsibilities and maximum time periods between each stage of the repair process (supported by drawings where required).
- Surface preparation requirements.
- Welding procedures (where applicable).
- Injection procedures (where applicable).
- Curing periods (where applicable).
- Bolt torquing requirements (where applicable).
- Coating requirements (where applicable).
- Details of when vendor or manufacturer supervision is recommended or mandated.
- Contact details for all key personnel.

- Health and Safety plan:
 - Hazard risk assessments / statements for equipment to be repaired and other equipment in the vicinity of the repair site.
 - Personal protective equipment (PPE) and measures.
 - Material safety datasheets.
- Requirements for work site cleanliness and process for ensuring that the work site is made safe following the repair.

4.5 Inspection and Test Plan

An ITP is a quality assurance tool which documents all of the key steps required to ensure the safe compliant installation of a repair. The extent of the ITP will depend on the type and complexity of the repair being undertaken but may include:

- Approved welding procedures (WPS), weld procedure qualification records (WPQR), welder qualifications (if known at time of issue), and weld maps, where applicable.
- Material tests.
- Surface preparation requirements and acceptance criteria.
- NDT requirements and acceptance criteria.
- NDT qualifications (if known at time of issue).
- Pressure testing requirements.
- Any special procedures required for example specific bending requirements, pre or post weld heat treatment (if required).
- Coating application requirements and acceptance criteria.
- Schedule of works (timeline or Gantt chart).

The ITP must clearly show all hold, witnessing, surveillance, testing, and documentation points for all parties involved i.e., manufacturer internal sign off, 3rd party sign off, Notified Body/local authority sign off, and end user sign off. Consideration should also be given to the competences of surveillance personnel for repair type.

The ITP must be approved by the end user prior to the commencement of any work.

4.6 Post installation Requirements

After successfully installing the repair, it may be necessary to document post installation requirements to cover the period of time between the repair being installed and it being removed/replaced.

The minimum expectation would be to document the installation of the defined-life repair under a management of change to record and inform the appropriate disciplines of the change and to define its planned removal date. For long-term defined-life repairs, base documents (e.g. P&IDs, GA and other) could be updated or red-lined showing the changes to the system.

Updating of the inspection program should be considered to implement follow up inspections to verify that the repair remains fit-for-service. The nature of the inspections performed will depend on the specifics of the defined-life repair installed and could range from a simple visual inspection to additional NDT at fixed intervals, the periodicity of which, for safety critical repairs, shall be such that the integrity of the system remains assured. Where in service degradation is possible, follow up examinations should be implemented to ensure that the defect does not grow beyond the assumptions used in the design of the defined-life repair (e.g. loss of structural integrity at clamp contact points or full circumferential corrosion resulting in loss of axial strength). Refer to section 6. The frequency of any follow up inspections shall be fixed such that the integrity of the line remains assured.

Other issues to consider documenting should include:

- Documenting the disposal of unused materials and waste (especially important for hazardous materials e.g. Asbestos containing gaskets or insulation).
- Assessing the need to review the fire rating or winterization of the repaired component.
- Scheduling the removal of the defined-life repair and planning a permanent repair / replacement.

5 Carry Out the Repair

5.1 Installation of Repair

The repair should be installed in-line with the requirements of the repair method statement and ITP (Section 4). Any deviation from the agreed repair method statement must be recorded. Where the repair is installed by another party other than the repair designer, the latter should be consulted, and the method statement updated. Additionally, the equipment owner / user shall be consulted and accept or reject all deviations. The effects of all deviations, should be considered when deciding whether to proceed with the repair. Where the decision to proceed with the repair is undertaken, it shall be proven that mitigation have been implemented such that the deviation will not impair the integrity of the repair over its defined life.

Following the installation of the repair, the neighboring areas of the line(s) should be walked down to verify that they have been appropriately reinstated and are fit for continued service (e.g. coatings, heat tracing, insulation, pipe supports have been reinstated where applicable).

Where a repair cannot be installed due to previously unassessed issues, this should be documented and reviewed by the equipment owner / user.

All defined-life repairs should be subjected to an examination following installation to verify the success of the repair and confirm compliance with QA/QC requirements. A defined life should also be assigned to each defined-life repair, specifying the planned removal date.

5.2 Defined-life Repair Register

All defined-life repairs must be identified and tagged with a unique tag number. As a minimum the tag number should allow cross-reference to the repair documentation. Where possible the tag may also contain additional information to aid identification in the field such as date installed, agreed date of removal, design pressure and temperature etc. A process for the colour coding of defined-life repairs at locations where they are installed may also be useful as it will improve visibility and encourage review or installation of permanent repairs. Furthermore, details of defined-life repairs should also be included on modification / redline drawings.

As a minimum all defined-life repairs must be recorded. It is good practice to maintain a controlled register or database of all defined-life repairs as this allows quick reference to all of the defined-life repairs and their status. Information to include in the Defined-life Repairs Register can include, but is not limited to:

- The unique identifier (tag ID) for the defined-life repair.
- The type of repair (wrap, clamp, etc).
- Design/process conditions (pressure and temperature).
- Date of installation and responsible individual/company.
- Specific location of the repair.
- QA/QC documentation taken during installation.

- References to approval documentation (e.g. Management of Change forms).
- References to the design calculations, drawings and materials used in the repair.
- Agreed date of removal or design life, including work order number for removal.
- References to the inspections or mitigation controls to be applied, including scopes and intervals.
- References to any planned maintenance for the equipment.
- Any comments or conditions at time of close-out (i.e. removal of defined-life repair / made permanent).

5.3 Documentation

Relevant documentation should be collated and retained for the life of the repair.

5.3.1 During Repairs

Key documentation that captures the work performed during the installation of the repair should be recorded and retained. The key documentation will vary depending on the type of repair performed, typically documents could include:

- Repair method statement (Any changes made to the prepared method statement during installation must be recorded).
- Technicians / Installer details (names / certificates / qualifications).
- Environmental data (humidity / temperature).
- Surface preparation records.
- Materials certificates / datasheets.
- ATEX / Calibration certificates for installation equipment (where applicable).
- NDE records (refer to ITP).
- Any other records or checks made during the installation of the repair.

Repair specific documentation is highlighted against repair types in the Appendix A.

5.3.2 Post-Repair

Where additional integrity tests or checks are performed after the installation of the repair, any relevant documentation should be recorded and retained. The key documentation will vary depending on the type of repair performed, typically documents could include:

- NDT certificates.
- Pressure Test certificates / Charts (if applicable).
- Calibration certificates for installation equipment (where applicable).
- Coating details.

Repair specific documentation is highlighted against repair types in the Appendices.