HSE
Health & Safety
Executive

Review of corrosion management for offshore oil and gas processing

Prepared by **Capcis Limited**
for the Health and Safety Executive

OFFSHORE TECHNOLOGY REPORT

2001/044

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Review of corrosion management for offshore oil and gas processing

Capcis Limited
Bainbridge House
Granby Row
Manchester
M1 2PW
United Kingdom

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EXECUTIVE SUMMARY

The document has been produced in response to an initiative led by the Offshore Safety Division of the UK Health and Safety Executive (HSE) and supported by the UK offshore industry. The primary objective of the initiative is to contribute to a reduction in the number of reported hydrocarbon releases in the UKCS, which can be directly attributed to corrosion. This goal is to be achieved through an industry wide improvement in corrosion management practices.

This document has been written following consultation with a large cross section of UK Offshore Operators, specialist contractors and independent verification bodies who provide corrosion services to the offshore oil and gas industry. Their input was sought via steering group discussion meetings, through interviews with relevant personnel, and the provision of example information, illustrating the application of their corrosion management process.

The aim of this document has been to capture "best practice" from industry on corrosion management for offshore processing facilities into a single document that will be in the public domain. Whilst the many of the problems and solutions described in this report are applicable to all aspects of oil & gas production, including design, installation, production and transportation for onshore and offshore facilities, the report is focused on operational aspects for offshore process plant and facilities.

Corrosion management also covers other integrity risks, including those from stress corrosion cracking, embrittlement, erosion, etc., as well as “simple corrosion” (i.e. general, pitting and crevice corrosion).

It is recognised that there are many ways to organise and operate successful corrosion management systems, each of which is asset specific depending on factors such as:

- Design
- Stage in life cycle
- Process conditions
- Operational history

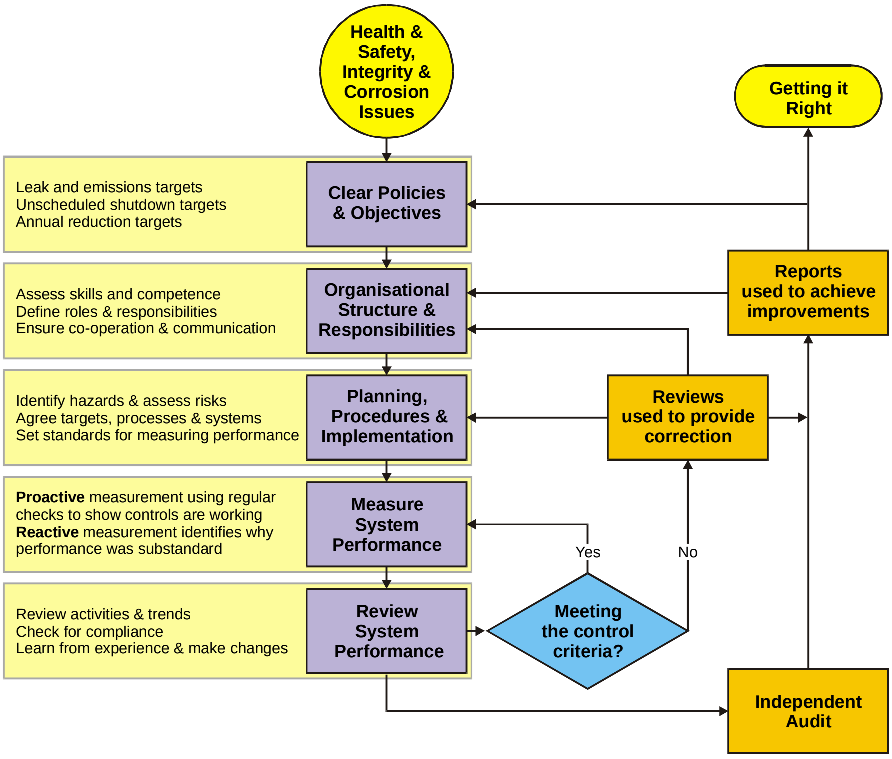
It is not intended for this document to provide a prescriptive framework for corrosion management but to outline techniques which have been demonstrated as successful in the identification and management of the risks posed by corrosion to offshore processing facilities.

Within this document corrosion management is defined as:

> ***“Corrosion management is that part of the overall management system, which is concerned with the development, implementation, review and maintenance of the corrosion policy.”***

The corrosion policy provides a structured framework for identification of risks associated with corrosion, and the development and operation of suitable risk control measures.

A general corrosion management system has been outlined that provides a progressive framework that is compatible with the requirements of an offshore safety management system concerned with ensuring the integrity of topside processing equipment. That is, employers should have effective plans and organisations to control, monitor and review preventative and protective measures to secure the health and safety of employees.



Basic Corrosion Management Process

Such a system, can operate at various managerial and technical levels within an organisation. The degree of complexity will depend on both the size of the operation - the number of personnel, the roles and responsibilities of managers, engineers, technical support staff and contractors. The system will also have technical input in terms of risk assessments for safety-critical items and control systems to ensure availability of chemical treatment use of corrosion inspection and corrosion monitoring. These are in turn determined by the materials of construction (corrosion resistant alloy versus carbon-steel), the fluid corrosivity, water cuts, age of the production system and maintenance strategies adopted.

Practical experience from the North Sea has shown that the development of comprehensive corrosion management systems, coupled with a commitment by both the operator, maintenance contractor and specialists sub-contractors / consultants, can lead to a major improvement in the operation of offshore topside process facilities.

BACKGROUND

The document has been produced in response to an initiative led by the Offshore Safety Division of the UK Health and Safety Executive (HSE) and supported by the UK offshore industry. The primary objective of the initiative is to provide information that will contribute to a reduction in the number of reported hydrocarbon releases in the UKCS, which can be directly attributed to corrosion [1]. This goal is to be achieved through an industry wide improvement in corrosion management practices.

Whilst the focus of this document is on hydrocarbon containment, it is also recognised that the good practices described within will be equally applicable to the prudent management of non-hydrocarbon systems (e.g. water injection systems, produced water systems, deluge systems, etc.) as well as other business critical systems; where loss of containment has a detrimental impact on operation of the facility.

Similarly this document is aimed directly at offshore topside processing facilities. The overall framework, however, can be adapted to include other areas where corrosion is an issue, including: subsea facilities, pipelines, onshore process facilities etc.

This document has been written following consultation with a large cross section of UK Offshore Operators, specialist contractors and independent verification bodies who have a role in corrosion control in the offshore oil and gas industry. Their input was sought via steering group discussion meetings, through interviews with relevant personnel, and the provision of example information, illustrating the application of their corrosion management process. The information gathered has been collated and reviewed to identify commonalties in the approach taken to corrosion management across the industry. "Best practice" examples are used throughout this document to illustrate points where appropriate.

ACKNOWLEDGEMENTS

The Health & Safety Executive, together with CAPCIS Ltd, acknowledge the help and assistance provided by the following companies and individuals working in the offshore industry in the preparation of this report.

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BP	Shipping	Tischuk International
CAPCIS Ltd	Marathon Oil UK Ltd	Torch Integrated
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Margaret Beardsley	John Dawson	Don Liddle
Ken Bruce	Andy Duncan	Brian McLoughlin
Thierry Chevrot	Irene Hannah	Keith Naylor
Jonathan Clark	Phil Horrocks	Richard Waud

[1] *Offshore Hydrocarbons Releases Statistics*, 1996. Offshore Technology Report OTO 96 954. Health and Safety Executive.

CONTENTS

1. INTRODUCTION

1.1 PURPOSE

This document has been written to provide assistance to individuals and organisations within the oil and gas industry in the development and operation of Corrosion Management Systems for offshore topsides processing facilities.

1.2 SCOPE

The aim of this document has been to capture "best practice" from industry on corrosion management for offshore processing facilities into a single document that will be in the public domain. Whilst many of the problems and solutions described in this report are applicable to all aspects of oil & gas production, including design, installation, production and transportation for onshore and offshore facilities, the report is focused on operational aspects for offshore process plant and facilities.

Corrosion management also covers other integrity risks, including stress corrosion cracking, embrittlement, erosion, etc., as well as “simple corrosion” (i.e. general, pitting and crevice corrosion).

It is recognised that there are many ways to organise and operate successful corrosion management systems, each of which is asset specific depending on factors such as:

- Design
- Stage in life cycle
- Process conditions
- Operational history

It is not intended for this document to provide a prescriptive framework for corrosion management, but to outline techniques which have been demonstrated as successful in the identification and management of the risks posed by corrosion to offshore processing facilities.

The success of any corrosion management system is reliant upon auditing and measurement of performance. Audit and measurement activities also contribute feedback ensuring continuous improvement in corrosion management activities. To assist in these activities this document contains checklists for self-assessment of corrosion management systems.

Within this document corrosion management is defined as:

> ***“Corrosion management is that part of the overall management system, which is concerned with the development, implementation, review and maintenance of the corrosion policy.”***

The corrosion policy provides a structured framework for identification of risks associated with corrosion, and the development and operation of suitable risk control measures.

1.3 WHY MANAGE CORROSION?

It is widely recognised within the oil and gas industry that effective management of corrosion will contribute towards achieving the following benefits:

- Statutory or Corporate compliance with Safety, Health and Environmental policies
- Reduction in leaks
- Increased plant availability
- Reduction in unplanned maintenance
- Reduction in deferment costs

The current statutory regime applicable to UK offshore oil and gas processing facilities places a requirement on the duty holder to maintain the integrity of the facilities, and to ensure that equipment can be operated safely and a safe working environment maintained. Loss of hydrocarbon containment on offshore processing facilities due to corrosion can result in severe consequences upon safety, the environment and asset value.

An analysis of data on offshore hydrocarbon releases reported by industry ranks corrosion as the second most frequent initiating factor leading to a loss of containment. Failures of joints and flanges rank most frequent. [2].

Predicting the rate of plant degradation due to corrosion carries an element of uncertainty. Uncertainty can be reduced by corrosion management systems that combine both proactive and reactive management measures.

There is an existing recognition by the UK Oil & Gas Industry of both the costs borne by their business, that can be attributed to inadequate corrosion control, and the consequential impact upon operations.

Cost implications are thus both direct and indirect:

DIRECT COSTS	INDIRECT COSTS
Inspection Chemical inhibition Corrosion monitoring Coating maintenance	Increased maintenance Deferred production Plant non-availability Logistics

The effect, therefore, of implementing appropriate Corrosion Management Systems, that result in the reduction/elimination of corrosion related damage/deterioration of assets, not only assists in compliance with regulatory requirements but also has a direct effect on the assets overall economic performance, i.e. providing a "double pay back".

2 '*Evaluation of Process Plant Corrosion/Erosion Incidents*', HSE Offshore safety Division Permanent Background Note PBN 99/4

1.4 LEGISLATIVE FRAMEWORK

The main current applicable UK legislation governing activities on topsides processing facilities for offshore installations includes:

- Health and Safety at Work etc Act 1974 (HSW Act)
- Management of Health and Safety at Work Regulations 1992 (SI 1999/3242) (MHSWR)
- Offshore Installations (Safety Case) Regulations (SI 1992/2885) (SCR)
- Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 (SI 1996/913) (DCR)
- Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (SI 1995/743) (PFEER)
- Provision and Use of Work Equipment Regulations 1998 (SI 1998/2306)

These regulations provide a framework (Figure 1) whereby risks are identified through a structured approach and an appropriate set of risk control measures are developed and implemented to manage them.

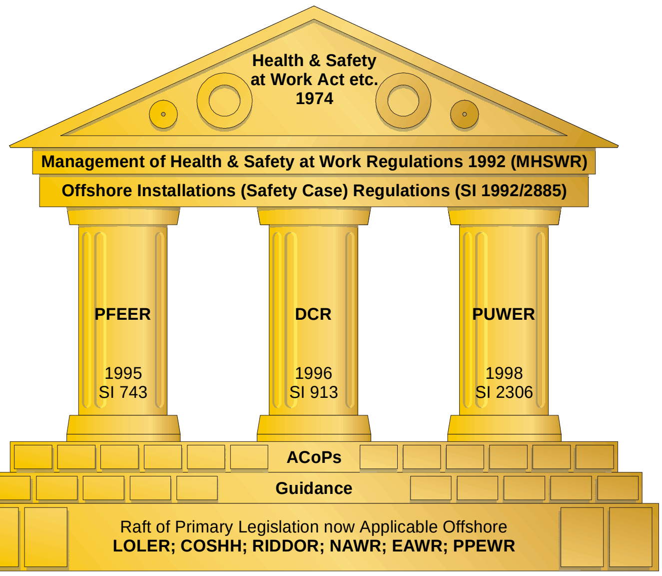

Figure 1. Schematic of Legislative Framework *

The goal-setting regime of these offshore regulations does not specifically state a requirement to manage corrosion. The emphasis placed on the duty holder by these regulations is on the management of corrosion to ensure system integrity and hence safe operation of facilities. Demonstration of regulatory compliance requires the duty holder to ensure that their management systems contain appropriate measures to identify corrosion risks, where these pose a threat to the safety or integrity of the facilities, and to manage those risks.

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* Diagram courtesy of Lloyd Register of Shipping

1.5 STRUCTURED FRAMEWORK FOR CORROSION MANAGEMENT

In the operation of an offshore oil & gas facility, the management of corrosion lies within the function of many parts of the duty holder's organisation and increasingly extends into contractor organisations. It is therefore important that corrosion management activities are carried out within a structured framework that is visible, understood by all parties and where roles and responsibilities are clearly defined.

The key elements of such a framework, based on an existing HSE model,[3] are illustrated in Figure 2. Sections 2 to 7 of this document illustrate, stage by stage, how this framework is being used in the context of managing corrosion, and discusses the key points, which can be considered as "best industry practice".

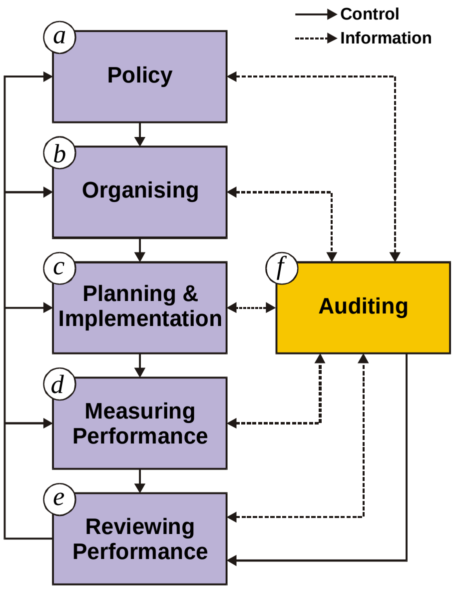

Figure 2. Framework for Successful Corrosion Management [3]

a. The **overall policies** adopted by an organisation. *(Section 2)*
b. The **role and responsibilities** of managers and staff within the organisation, including the development and maintenance of appropriate strategies. *(Section 3)*
c. The **development of plans and procedures**, plus the means of implementation of various corrosion control measures. *(Section 4)*
d. The methods adopted for **performance measurement** of the system against pre-determined criteria. *(Section 5)*
e. The use of systematic and **regular reviews** of system performance. *(Section 6)*
f. The use of **periodic audits** of the management and monitoring systems. *(Section 7)*

Steps (a) to (e) are concerned with the setting up and operation of a management system, whilst step (f), auditing, ensures that the overall structure is operating and that lessons are learnt and fed back for future improvement.

The simple framework shown in Figure 2 is expanded for use throughout this document (Figure 3). Figure 3 shows the specific feedback loops necessary for control, review, audit and reporting purposes.

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3 "*Successful Health and Safety Management*", HS(G) 65, HSE Books 1991, ISBN 0-11-882055-9

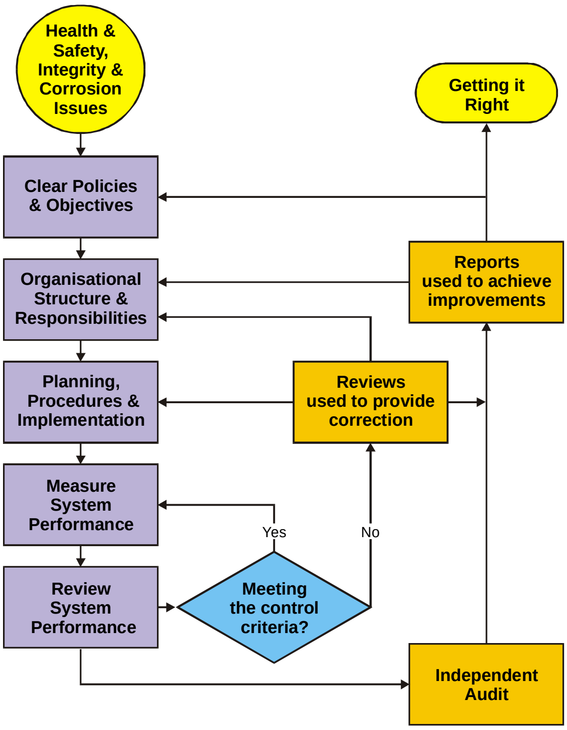

Figure 3. Development of the Management Process

A structured approach such as this is typically adopted, for instance, by Total Quality Management (TQM) schemes [4] and used to control risks within organisations. The successful operation of such procedures is often indicative of management commitment to continuous improvement in performance.

The approach adopted by operators to the management of risks associated with corrosion and/or installation integrity is generally similar to that adopted for management of safety risks, as required by legislation for the safety case.

The interface is the corrosion management strategy with output as implementation through documentation. Weaknesses in management systems tend to occur not with the front-end steps (the strategies/policies/planning/data gathering/review) but towards the later steps of the process (recommendations/actions).

The practical means of achieving specified objectives (minimum leakage and downtime) requires guidelines, codes and standards for specification of the works (the tactics) plus suitable management procedures and systems (the strategic means). The linking of strategy and tactics as part of a Corrosion Risk Assessment is important because responsibility for the day-to-day management of corrosion may be split between groups or individuals, hence procedures must be in place to ensure that overall control and responsibility are both measurable and effective.

In this document an "idealised" corrosion management system is described, in which all the different tasks / actions necessary are carried out in isolation. In practice many corrosion management systems will combine two or more tasks / actions to the same effect. The over riding requirement is to ensure that the different tasks / actions are completed, rather than the exact organisational arrangement.

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4 "*Total Quality Management*" J.S Oakland Pub. Butterworth – Heinemann Ltd, Oxford, 1995, ISBN 0 7506 21249

1.6 RISK CONTROL SYSTEMS

Installation integrity and safety has to be managed at all stages of an installations life cycle, as required by the Design and Construction Regulations. This will involve development of those sections of a duty holder's organisation and specialist organisations (internal consultants and external contractors) so that they can deliver support in the different areas of responsibility. HS(G)65 [3] addresses this aspect of the management process by means of Risk Control Systems (RCS).

RCS are process evaluations whereby each group within an organisation, specialist contractor and associated activities, are assessed by consideration of three basic stages:

- The input into the group/activity
- The processing or actions undertaken
- The output or measured performance

Development of a framework for Corrosion Management for a particular facility requires the application of RCS. This document assumes familiarity with the application of RCS methodology but further details are included in Appendix A together with example applications.

2. POLICY AND STRATEGY

2.1 PURPOSE

This section will outline the basis of a common approach to setting corrosion policy and clear strategic objectives. A "policy" is in principle permanent, having the authority of the most senior manager of the unit to which it is intended to apply.

A policy is a directive that specifies how a major operational issue should be handled over the longer term. It forms a basis for subsequent detail in terms of strategies, organisation structures, performance standards, procedures and other managerial processes. The corrosion strategy is the method by which the policy is implemented.

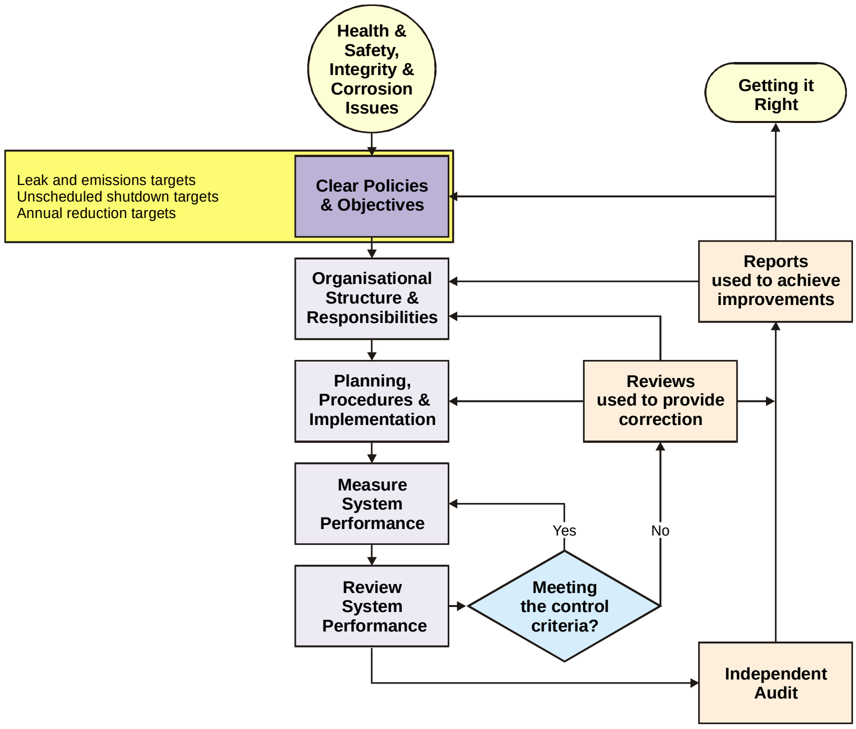

Figure 4. Setting the Policy

2.2 SCOPE

All organisations should have in place policies and strategies that deal with hazards and risks associated with safety, health and environmental concerns. Thus, although many companies may not have a stated corrosion policy, all accept the inherent concept of good corrosion management practice is implied and is incorporated into their planning process.

Development of strategies for corrosion management involves many managerial and technical functions and impacts upon various levels within the duty holder and its contractors/sub-contractors. Of most importance are:

- **Overall management of corrosion risks**
    - Ensuring responsibility for corrosion management resides with a named individual whose authority should be equal to his responsibility
    - Ensuring roles and responsibilities match the required competency

    - Integrating corrosion management with safety and asset management and to inspection, maintenance and operations strategies
    - Ensuring that risk assessment procedures remain live and are updated on a regular basis
    - Providing an auditable trail for corrosion risk/criticality assessments
    - Ensuring feed back from field experience into new designs and particularly that adequate corrosion input occurs at the concept stage

- **Effective deployment of human resources**
    - Ensuring adequate resources are available
    - Ensuring technical and managerial competence, particularly where:
        - Multi-skill manning is involved
        - Corrosion issues are delegated and become the responsibility of a non-specialist
    - Involving all appropriate team members in sharing of information
    - Evolving a proactive culture

- **Development of appropriate organisational structures**
    - Ensuring key information gets to the right people
    - Using appropriate information control systems

- **Systems to meet changing situations**
    - Ensuring process fluids are monitored to identify changes in corrosivity
    - Updating and auditing all systems when implementing organisational changes
    - Providing benchmarks and audits from which to develop future strategies
    - Developing opportunity based inspection procedures

Example 1. Ownership
The complex interaction/inter-relationships required for corrosion management may require that some aspects of corrosion control responsibility (i.e. chemical injection) lie with production, whilst others (i.e. inspection) are the role of maintenance or inspection departments. *More specialist areas (i.e. cathodic protection, coating applications, corrosion monitoring etc.) may be carried out by specialist sub-contractors, whilst overall advice and guidance will be provided by either in-house or third party corrosion engineers and materials specialists.* *It is, therefore, important that the corrosion management system provides clear guidance for all individuals and organisation involved. In order to achieve this it is important that there is clear ownership of the corrosion management system.*

2.3 EXPECTATIONS

Corporate policies must establish clear, high-level objectives. The majority of operators incorporate their corrosion management policy, either directly or indirectly, within their overall facility integrity policy. A few operators, however, state specific corrosion management policies:

Example 2. Specific Corrosion Management Policies

- *No leaks or emissions*
- *Minimum 20% reduction of corrosion related failures year on year*
- *Pursue reduction of emissions and, where reasonably practicable, eliminate them*

Many organisations also further break down their policy statements into more specific expectations or objectives for each major activity.

"**Business Units**" with responsibility for processing equipment integrity may apply a general corporate policy for some activities, such as selection of contractors and training, but then develop specific expectations and objectives for inspection, maintenance and management of corrosion.

Policy statements together with subsequent expectations and objectives form the basis for management to measure and audit the effectiveness of the organisation. Companies may also develop "**performance standards / indicators**", which are then used to measure the extent (or otherwise) to which the policy objectives are met.

2.4 BEST PRACTICE

The industry recognises that corrosion control is an integral and vital issue for safety of offshore installations.

The industry has also noted the positive effect of the new UK Offshore legislation, which has forced cross-departmental discipline together with full commitment to the management of the interfaces across all organisational levels.

Example 3. Establishing Corrosion Policy

- *Some operators conduct all activities associated with the setting up and operation of corrosion management/asset integrity in-house through internal specialist groups, who set and develop the corrosion policy and the corrosion strategy.*
- *Other operators appoint specialist contractors to set up the corrosion policy and corrosion strategy for ratification by the operators. Some operators will appoint a single specialist contractor to cover all activities, whilst other operators will use different specialists (internal/external) for specific activities, viz:*
    - *The setting up of the system and procedures*
    - *The operation of the system*
    - *The verification/audit*

Example 4. Link Step Approach

One successful approach to development of corrosion policy and strategy is the "link step approach" as shown in Figure 5. Inputs into the Review of External Factors include Safety, Economics and Operation. Strategy inputs are from a corrosion risk analysis that then results in a corrosion control matrix and roles and responsibilities for implementation.

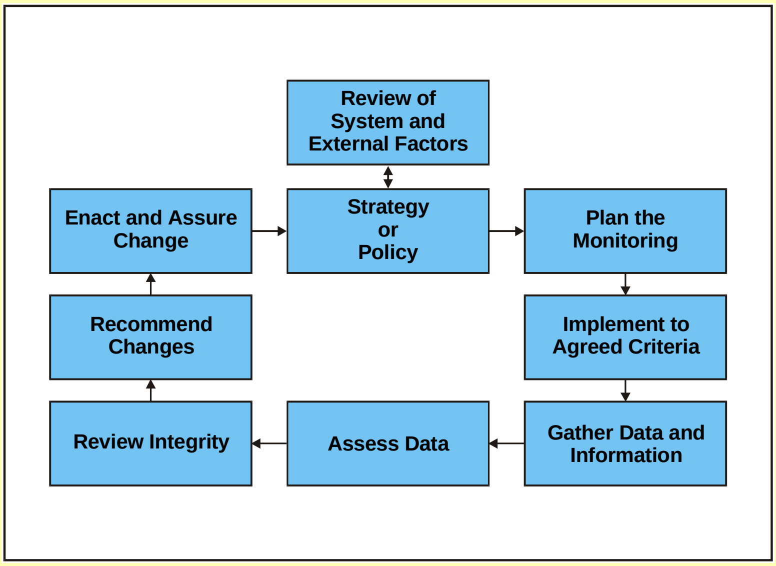

Figure 5. Management Support of Offshore Safety Case

It should be noted that a clear company policy statement, that provides guidance to the corrosion strategies to be adopted to ensure integrity, indicates commitment from senior management and ensures that the correct corporate culture is established.

3. ORGANISATION

3.1 PURPOSE

This section provides a framework for and examples of how a corrosion strategy helps in the allocation of roles and responsibilities both within the duty holder's organisation and contractor/sub-contractor organisations.

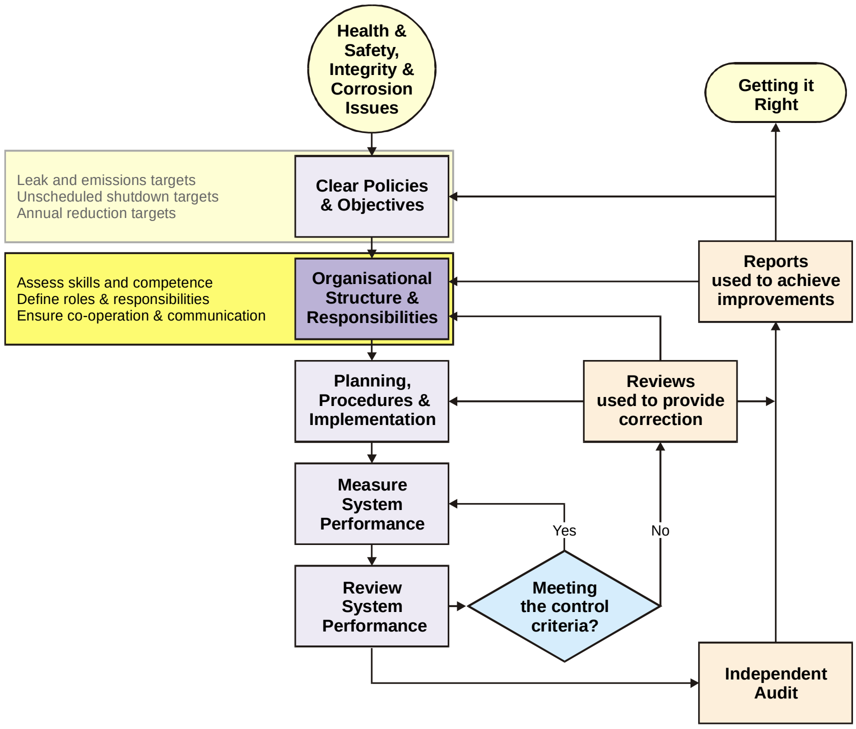

Figure 6. Identify Ownership of the Corrosion Management Process

3.2 SCOPE

The effectiveness of any policy depends on the leadership, commitment and involvement of managers and senior staff. Safety is of concern to everyone; employer, employee and contractor. Corrosion should also be of similar concern. A positive "health and safety culture" and "corrosion culture" means less risk to individuals and less damage to the integrity of a facility.

For organising corrosion management the four "Cs" of a positive culture are:

- Control
- Communication
- Competence
- Co-operation

Consideration of the four Cs is vital, particularly for management of complex multi-disciplinary areas, like corrosion management, which may well involve non-specialist engineers.

3.3 TEAM MEMBERS

For the planning and implementation of the corrosion management system, the corrosion team members, along with their roles and responsibilities, should be clearly defined.

The location of the Technical Authority for corrosion should also be identified. The strategy adopted should describe the links between the parties involved with corrosion management. This is particularly important where alliances between owner, contractor and specialist sub-contractors and consultants exist.

3.4 CONTROL, COMMUNICATION, COMPETENCE & CO-OPERATION

- Control
  - Allocate responsibilities and authority
  - Ensure that managers, supervisors and team leaders have the time and resources needed
  - Identify key areas that require special expertise, e.g.
    - Corrosion inhibition
    - Use of Corrosion Resistant Alloys
    - Corrosion prediction
    - Cathodic protection
    - Microbiologically influenced corrosion problems, etc

- Communication
  - Provide written information on hazards, risks and preventative measures
  - Organise regular discussion meetings on issues
  - Ensure visibility of managers, supervisors and, when appropriate, specialists including contractors
  - Share experiences with external bodies
  - Dissemination of appropriate information to the correct people

- Competence
  - Management of corrosion risks requires all involved to have qualifications, experience and expertise appropriate to clearly defined duties and responsibilities
  - Training may be required to ensure that those having responsibility understand the issues
  - Seek out experienced personnel and external advisors for advice where necessary
  - Ensure all involved have appropriate training, understanding of the risks, understanding of the working practices and awareness of their own role, their own limitations and the limitations of those for whom they are responsible

- Co-operation
  - Control of risks requires input from managers, designers, operational staff and maintenance engineers, inspection departments, corrosion engineers and consultants
  - Consult staff for opinions and involve staff in planning and reviewing performance
  - Co-ordinate with contractors
  - Co-ordinate with external bodies

There are many different ways the above can be achieved. This will be dependent on the size of the organisation, and the extent or otherwise that various duties and responsibilities are contracted or sub-contracted out to third party organisations.

Example 5. Matrix Style Arrangement

A good example for a single asset operator, with a small core team of engineers is a matrix style arrangement. Under this arrangement the different discipline engineers (mechanical, electrical, process, materials/corrosion, etc.) as well as having a responsibility across the asset relating to their specific discipline, also have direct functional responsibility for parts of the process facility itself (for example produced water, processed gas, water injection etc.). In this way, communication between different areas/disciplines is maintained.

Example 6. Common Corrosion Management System

For a large operator, with multiple assets (both new and mature) one good example has been the adoption of a common Corrosion Management Assurance System across all assets. This has been fully documented and controlled by the operator and implemented by the operator and their prime contractors (see Figure 7).

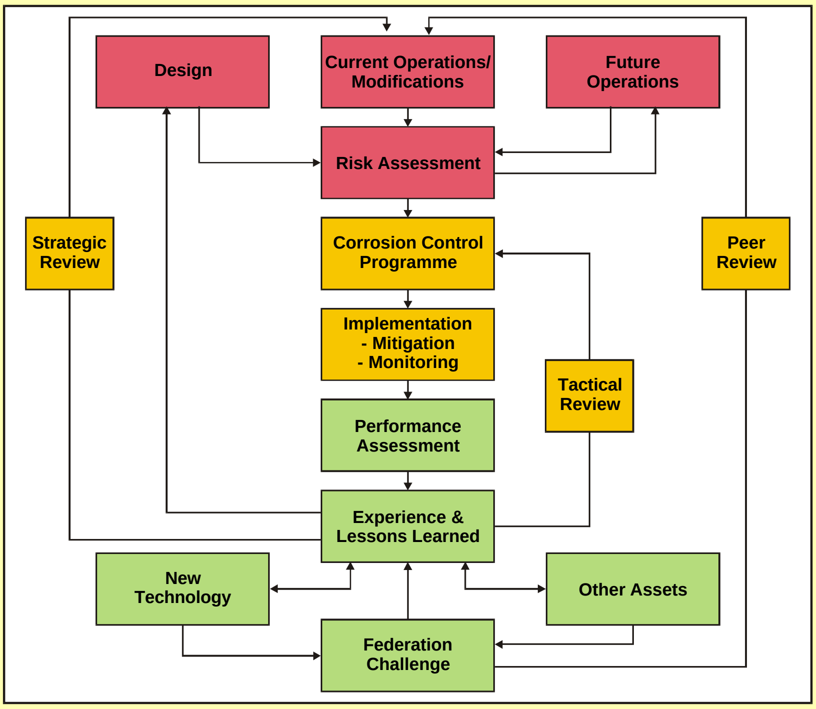

Figure 7. Corrosion Management System Applied Across Assets

Example 7. Facilities Change Control Procedures

As part of any organisation the management of change is vital. Any proposed or planned changes in process; for example bringing on new wells, or changes in secondary recovery systems, could have a major impact on the corrosivity of the fluids. Procedures are, therefore, incorporated to ensure that whoever has responsibility for corrosion/materials are included in the reviews conducted under Facilities Change Control Procedures.

The issue of competence across the corrosion management structure is also important. The actual implementation, in particular the inspection activity, is well described by various national and international standards and codes-of-practice, such as ASNT [5], CSWIP [6], PCN [7] and EEMUA [8].

However, there are at present no equivalent requirements for the setting of the corrosion management plan, for data analysis, for the interpretation of results or for providing recommendations for corrective action. Most operators & contractors will appoint suitably experienced and qualified corrosion and/or materials engineers either to supervise or to carry out this activity, but there is no uniformity in the level of experience or qualification required.

Example 8. Competency Guidelines

A good example for determining the level of competence required for a particular activity, as well as the degree of competence provided by individuals, has been developed by the Institute of Electrical Engineers [9] which could be adapted for use in the offshore oil & gas industry to apply to corrosion management issues.

In addition to the need for personnel to have technical skills appropriate to the role, experience, expertise, knowledge and understanding of the area for which they are responsible is necessary along with behavioural skills relating to, for example, appropriate attention to detail, interpersonal skills and problem solving abilities.

The level of skill, experience and expertise will vary depending upon the duties and responsibilities.

- Supervisor
  - Knowledge and understanding of the roles, responsibilities and corrosion management structure operated by the organisation
  - Experienced in successful review of processes and procedures
  - Experience of corrosion risk assessment and corrosion management techniques used offshore and is able to apply them

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5 American Society of Non-Destructive Testing

6 Certification Scheme for Weldment Inspection Personnel

7 Personal Certification in Non-Destructive Testing

8 Engineering Equipment and Materials Users Association, publication no 193:1999 "*Recommendations for the training and development and competency assessment of inspection personnel*"

9 *"Safety, Competency and Commitment: Competency Guidelines for Safety- Related System Practitioners"***,** pub by Institute of Electrical Engineers. London, ISBN 0 85296 787 X. A summary is also available on the internet at http://www.iee.org.uk/PAB/CompSafe/scc_snip.htm

- Corrosion Engineer
  - Familiar with relevant standards and specifications
  - Can identify, justify and apply measures required to minimise risks from corrosion
  - Has experience of corrosion risk assessments

Once the necessary skills, expertise and experience for each role have been defined, ongoing assessment of personnel can be beneficial. This ensures that the competence of individuals is appropriate, and is a method by which requirements for implementation of further training, for example, may be identified.

In Europe there are no recognised professional qualifications that cover a minimum level of expertise for Corrosion/Materials Engineers. The nearest is Professional Member of the UK Institute of Corrosion [10], that is MICorr or FICorr. However, there are many universities that offer specialist degrees in corrosion and/or material engineering at undergraduate or post-graduate (Dip, MSc or PhD) level and NACE International [11] also operates an internationally recognised Certified Corrosion Specialist scheme, based on a process of examinations and peer review.

Example 9. Corrosion Awareness
The use of Corrosion Awareness training programmes, aimed at the non-specialist, has been found to improve overall levels of corrosion performance. An inspection technician, maintenance operator or process chemist, who has a better understanding of corrosion and material degradation, including how it manifests itself, what causes it and the different options for control, ensures that: - *Signs of corrosion/damage are recognised at an early stage – allowing remedial measures to be put in place before damage requires major work* - *The reasons for the detailed requirements for inspection and monitoring are better understood – improving efficiency and co-operation* - *The effect of corrosion control measures are better understood – again improving efficiency and co-operation*

An important aspect is to ensure that offshore personnel are fully committed and involved in the corrosion management process, and that corrosion is not seen as just an "onshore support" activity.

10 Institute of Corrosion, Leighton Buzzard, UK

11 NACE International, Houston, Texas, USA

4. PLANNING & IMPLEMENTATION

4.1 PURPOSE

This section outlines the methods and key elements of planning and implementation, which forms the largest single part of any corrosion management process. The purpose being to ensure that the activities within the corrosion management strategy are carried out in a logical order in an efficient way that is fully auditable. Without planning the implementation of strategies becomes confused, diffuse, and likely to fail.

Planning and implementation covers both the collection of data relating to the condition and corrosion risk of the facility as well as the operation of the corrosion control / corrosion engineering activities required to ensure that deterioration is eliminated / minimised. This includes risk assessment, monitoring and inspection procedures, data collection / analysis and correction actions to control corrosion.

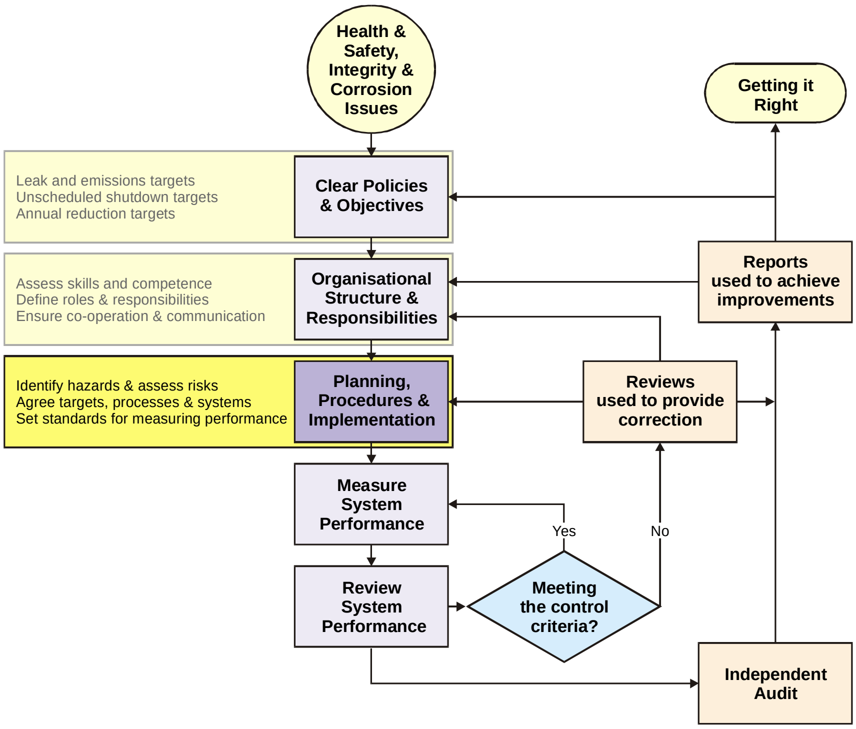

Figure 8. Planning is Vital For Success

4.2 SCOPE

Planning includes:

- The identification of corrosion threats and consequences
- Ranking of systems and components in order of corrosion risk
- Selection of appropriate mitigation and management activities
- Scheduling of tasks

Implementation ensures that actions identified in the planning stage are carried out as required and includes:

- Translation of the plan into a detailed set of work packs.
- Identification of the locations for monitoring and inspection activities
- Procedures for execution monitoring and inspection activities
- Development of acceptance criteria

- Development of performance measures
- Definition of the reporting routes
- Data gathering and management
- Analysis of data
- Reporting
- Corrective action/application of corrosion control measures.

Planning and Implementation constantly and rapidly influence one another through the internal flow of information. This constant "self regulation" works within the overall framework (Figure 8 and Figure 9)

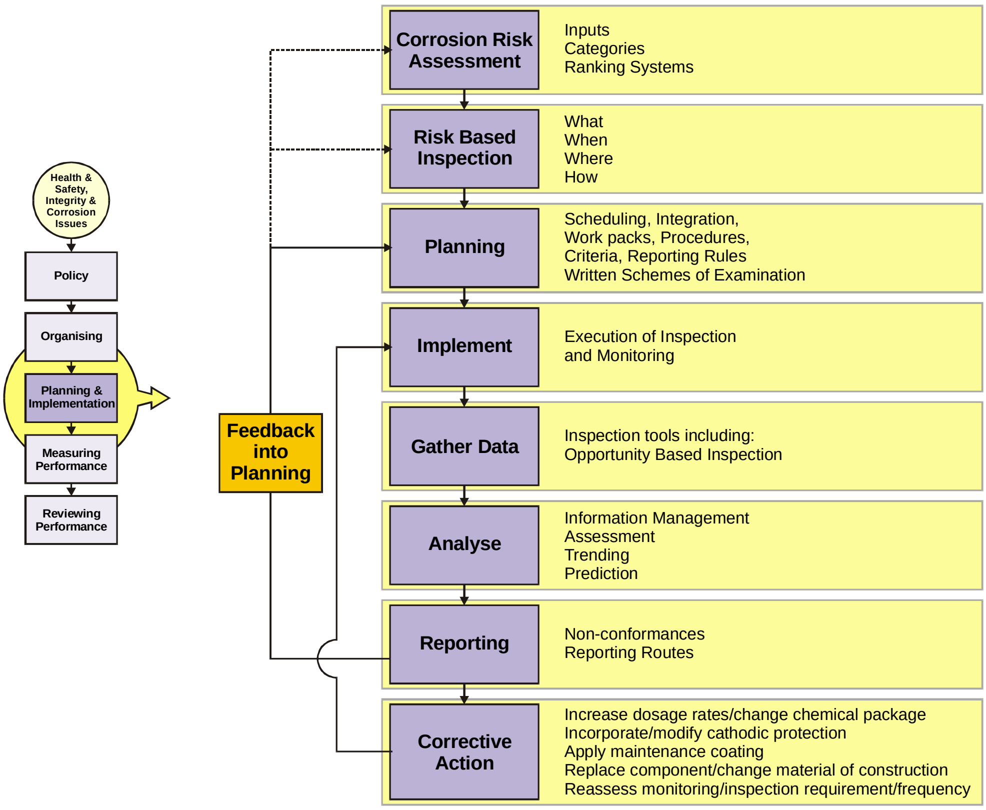

Figure 9. Planning & Implementation Process

4.3 EXISTING ASSETS OR NEW BUILD

The detail for implementation of corrosion management plans may differ significantly between new build facilities or assets and existing or ageing systems. New build provides an opportunity to incorporate all appropriate current best practice from concept stage through asset or field life. The requirement to systematically and continuously plan and implement an appropriate corrosion management system remains constant.

New Build - Inherent Safety

In addition to the specific legislative requirements, the planning process should encourage control of risks using the concept of inherent safety. The principles of inherent safety are more effective at the concept stage and detailed design stages. However, the same approach should be applied during operations when modifications and repairs are considered (design-out maintenance). The general principles include:

Example 10. Considerations for "New build" facilities
- *Explicit treatment at the earliest stages of concept design to eliminate, where possible, hazards associated with corrosion damage that combine with operational loads to produce failures, design assessments should look for sites of probable corrosion and consider the use of corrosion resistant materials or an other effective method of corrosion control.*   - *Design to minimise corrosion damage to safety critical items and systems.*   - *Ensure that key support structures for equipment have a high reliability and resistance to failure, this is important in areas exposed to marine environments and subject to wash down or regular deluge from tests of firewater mains.*   - *Selection of locations, configurations and orientations that minimise threats to the integrity of equipment, viz. design detailing of impingement/wear plates, drainage, and removal of deadlegs where corrosive conditions develop/ chemical treatments are ineffective.*   - *Design to survive local/component failure by maximising redundancy, viz, backup injection pumps for inhibitor injection systems.*   - *Design to allow more reliable and effective inspection, ensure adequate access for inspection/monitoring equipment.*   - *Design for maintainability – easy removal of pumps, motors, valves.*

Existing Infrastructure

One major factor that will impact on the corrosion management planning and implementation stage is planned asset life. Corrosion management planning should be based on the long-term corporate strategies and objectives for the production facility and therefore the corrosion risks need to be appraised against these objectives when planning and implementing corrosion control activities to meet the required asset life.

As technology advances asset life expectancy is increasingly being extended beyond originally designed time-scales. It is, therefore, important when planning to extend field life beyond design limits to be able to accurately gauge corrosion control status. Life extension may well require re-appraisal of corrosion risks and major changes to planned activities.

Throughout the planning stage the corrosion management strategy should agree with the current planned asset field life. Consequently, future business and operational requirements for an asset should, where practicable, be made known to those responsible for setting and implementing the corrosion management plan, as outlined in Example 11 and as shown in Example 12.

Example 11. Range of Operational Requirements for Existing Facilities
- *Assets may be deliberately managed with a limited operational life in mind* - *Limited life assets may be operated with reduced maintenance activity* - *After operational or financial reviews the asset may have its operational life extended by a few to many years.* - *Operational changes include incorporation of new/marginal fields, acting as a hub for other fields, or enhanced oil recovery* - *In the event of asset life extension the asset may only be viable after additional work and/or a significant change to its maintenance and corrosion policy*

Example 12. Impact of Planned Asset Life
A platform had been operated for over 4 years on the basis of a fixed End of Life based on the known recoverable reserves. During the period leading up to the expected abandonment limited inspection and maintenance was carried out - consistent with the planned abandonment date. *Just over a year before the platform was due to be abandoned the decision was taken to bring on a new marginal field - using extended reach drilling. This, together with other changes in the production process, meant the platform had an economically viable life extension of more than 6 years.* *The benefit, however, of the extended useful life was reduced due to the heavy cost of maintenance/repair/replacement of components that, because of the operational regime now had only a limited (less than 2 year) remaining life.* *If the options for the future of the asset had been made known to the relevant groups earlier, a different operation and maintenance regime would have been incorporated in the years leading up to the introduction of new field with considerable savings in the overall operational cost over the remaining life of the platform.*

4.4 GENERAL

Identification of hazards, assessment of risks and agreement on planned activities is a fundamental requirement of the management process. Planning and implementation often makes use of company guidelines, industry codes and international standards. Checks are also needed to determine whether they are appropriate and effective for each particular asset.

The ownership of actions and responsibilities relating to the corrosion management plan are vital to successful operation. As part of this process the duty holder should keep appropriate records of planning and implementation to allow full transparency of the process. In some instances this information may be incorporated into the relevant production facility Safety Case and Verification Scheme, which normally forms the basis for all integrity management requirements and specifications

4.5 CORROSION RISK ASSESSMENT

Planning should commence with a formal process to identify the components on a facility that have a risk of degradation due to corrosion. The most common approach to this is to conduct a Corrosion Risk Assessment.

The purpose of the Corrosion Risk Assessment is to rank the static equipment in relation to their corrosion risks and identify options to, remove, mitigate or manage the risks. If risks can not been removed, which is usually achieved through a change to the design, then the corrosion threat has to either be mitigated or managed. Mitigation is achieved through the use of different materials, application of coatings, cathodic protection and chemical inhibition. Management of corrosion risks is achieved through the introduction of a corrosion monitoring and inspection programme.

In the operational phase of the asset life cycle the primary intent of the corrosion risk assessment is to guide the inspection and corrosion monitoring activities in order to locate and measure potential corrosion problems. The Corrosion Risk Assessment is also used as the initial step for Risk Based Inspection systems, which are covered further in Section 4.6.

A Corrosion Risk Assessment is a formal review that identifies the probability of a corrosion-related failure and its consequences relating to the loss of containment and the consequential hazards should a failure occur.

Corrosion Risk is normally expressed as the product of the probability of a corrosion related failure and the consequences of such a failure where:

- **Probability of failure** is estimated based upon the types of corrosion damage expected to occur on a component, and
- **Consequence of failure** is measured against the impact of such a failure evaluated against a number of criteria, which as a minimum would include safety, environmental and operational impacts, which would result should a loss of containment occur.

Corrosion Risk Assessments can be carried out at two levels:

- A high-level "system" assessment which groups together components, which are constructed from the same materials and are subjected to the same process and operating conditions.
- A more detailed assessment, which looks at the vulnerability of specific components.

In each case the process facilities should be assessed for risks on the basis of:

- Internal corrosion threat
- External corrosion threat
- Safety/hazard threat
- Environmental threat
- Operability threat

Ideally the Corrosion Risk Assessment identifies the corrosion / degradation threats to each item of process equipment, assesses the remaining life, and feeds the information back into the overall risk assessment and control system. The Corrosion Risk Assessment may also be used to assign priorities for corrosion monitoring and corrosion management procedures, including input into Risk Based Inspection (RBI) schemes.

As part of any corrosion risk assessment the sensitivity of the different parameters (e.g. CO_2, H_2S, temperature, pressure, flow rate, water cut, etc) on the predicted corrosion rate should be assessed. This will allow identification of the more critical parameters, where closer attention to changes (in some cases even small changes) over the facilities operational life may be required. Increasingly *Monte Carlo* analysis methods are being applied to the predicted conditions, to identify the likely range and distribution of corrosion over the range of operating conditions. This allows a more reasonable approach to assessing risk, rather than relying on *worst-case scenarios.*

The Corrosion Risk Assessment model should ideally be maintained live throughout the asset life, and requires regular review of the data employed and the assumptions used. The results of the corrosion monitoring and inspection activities should be fed back into the Corrosion Risk Assessment model to validate its assumptions, or modify them accordingly. The review frequency may be considered a function of the rate of change of process conditions, as identified in Examples 13 & 14:

Example 13. Annual Review/Annual Validation

For non-stable process conditions detailed re-assessment would normally be required at least annually.

However, for stable process conditions, with good historical trend data, the regular (annual) review could consist of simply validating the process conditions and that the assumptions used in the Corrosion Risk Assessment are still valid, rather than running the entire risk assessment every time

Example 14. Minimise High Risk

Case examples exist where, by running the corrosion risk assessment several times during the first few years operation of an asset (based on a better understanding of the actual - as opposed to assumed – conditions) has resulted in progressively fewer items being considered as “high-risk”, thus reducing the requirements for inspection.

For example, the percentage of topside components that were categorised as a Grade 1 risk for a new platform changed from first oil over a 7 year period was:

Year	***Comments***	***% of Cat 1 Risk***
1993	*First oil*	*53%*
1997	*Second CRA review*	*39%*
1998	*Third CRA review (18 months later)*	*26%*
2000	*Fourth CRA review*	*20%*

Example 15. Inspection and Corrosion Monitoring Process

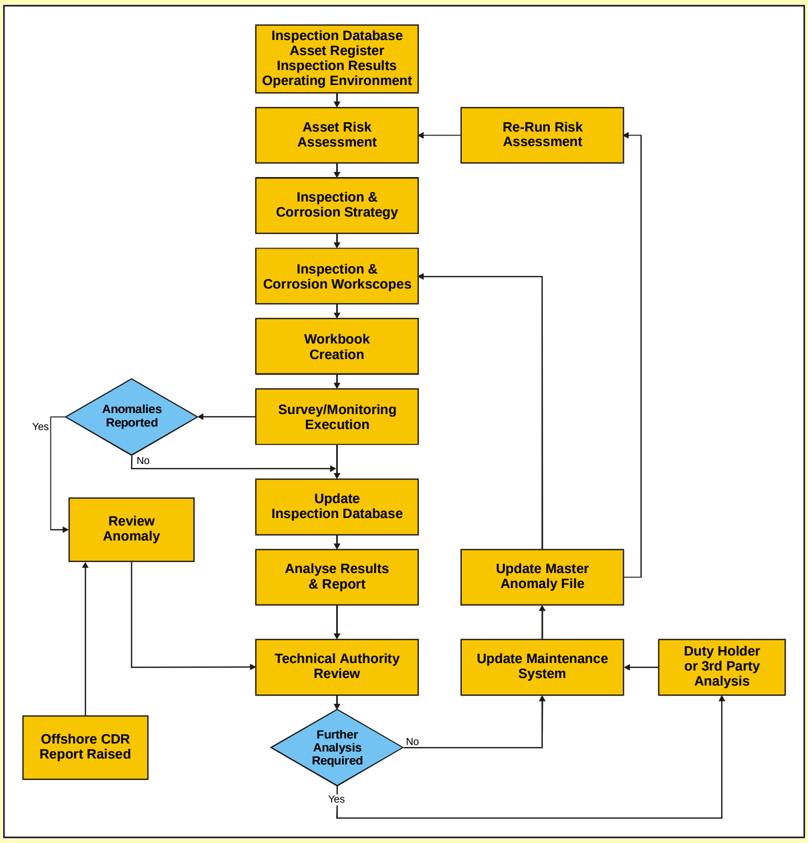

Figure 10. Example of Corrosion Monitoring & Inspection Planning and Data Analysis

4.6 RISK BASED INSPECTION

Risk Based Inspection (RBI) schemes are a planning tool used to develop the optimum plan for the execution of inspection activities. RBI uses the findings from a formal risk analysis, such as a Corrosion Risk Assessment, to guide the direction and emphasis of the inspection planning and the physical inspection procedures.

A risk based approach to inspection planning is used to:

- Ensure risk is reduced to as low as reasonably practicable
- Optimise the inspection schedule
- Focus inspection effort onto the most critical areas
- Identify and use the most appropriate methods of inspection

Risk Based Inspection methodologies are well described in published documents such as API 581 [12] or Det Norske Veritas RP G-101[13] and have been adopted by many operators, a typical implementation is shown in Example 16.

12 API Publ 581 "*Risk Based Inspection*"

13 DnV RP G-101, "*Risk Based Inspection Of Topsides Static Mechanical Equipment*", in draft, to be published in 2001

Example 16. Typical Risk Based Inspection Methodologies

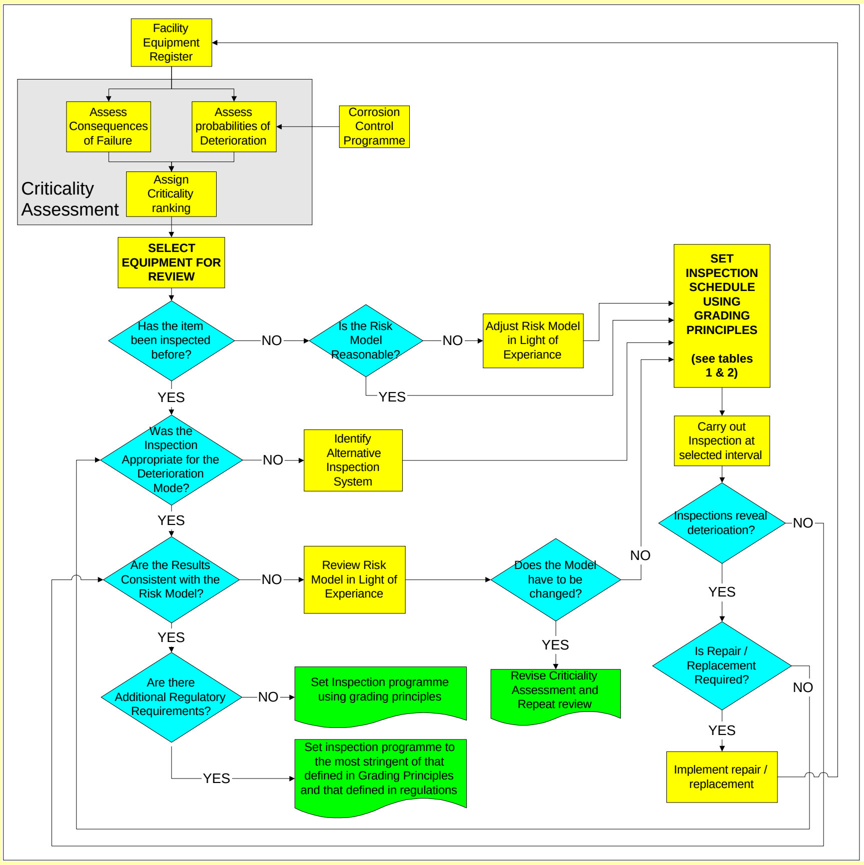

Figure 11. Example of RBI Planning

Grade 0 - Equipment allocated Grade 0 are items for which: *(a) there is insufficient evidence or knowledge of operational effects on which to predict behaviour in service*   *(b) the rate of deterioration is potentially rapid or*   *(c) the rate of deterioration is unpredictable.*
Grade 1 - Equipment allocated Grade 1 are items which have: *(a) at least one previous thorough examination at Grade 0 and*   *(b) a moderate rate of deterioration which is predictable and*   *(c) sufficiently reliable evidence of reasonably steady/stable service conditions consistent with the examination interval to be applied.*
Grade 2 - Equipment allocated Grade 2 are items which have: *(a) at least one previous thorough examination at either Grade 0 or Grade 1 and*   *(b) which show a low rate of deterioration which is predictable and*   *(c) sufficiently reliable evidence of stable operating conditions consistent with the examination interval to be applied.*
Grade 3 - Equipment allocated Grade 3 are items which have either: *(a) at least one thorough examination at Grade 0 and one examination at either Grade 1 or 2 and*   *(b) which show a low rate of deterioration which is predictable or*   *(c) sufficiently reliable evidence of a negligible rate of deterioration in a stable service environment such that an increased interval is justified*

Table 1. Guiding Principles Schedule for Risk Based Inspection

Example 16 continued

Criticality Rating	*Inspection Period (months)*				*Maximum Review Periods*
	Grade 0	*Grade 1*	*Grade 2*	*Grade 3*	
1 ***High Risk***	*24*	*36*	*N/A*	*N/A*	*12 months*
2	*24*	*48*	*N/A*	*N/A*	*24 months*
3	*36*	*48*	*72*	*96*	*48 months*
4	*36*	*48*	*84*	*120*	*60 months*
5 ***Low Risk***	*36*	*60*	*96*	*144*	*72 months*

Table 2 Varying Inspection Intervals based on Component Criticality and Grading Principles

Where such a Risk Based Inspection scheme is used, it should be noted that the determination of future inspection requirements, by extrapolation of historical trends, is based on an assumption that the conditions in the future are similar to those in the past and that there is no change in degradation mechanism(s). Any significant change in operating conditions (for example water break through, increase in CO_2 content, change in wax or scaling tendency, etc), could result in significant changes in corrosion rate and/or corrosion damage, which could in turn lead to different inspection requirements. It is therefore appropriate for the model which is driving the Risk Based Inspection scheme to be re-run either at specific time intervals, or when a process variable exceeds a previously agreed boundary condition.

On new assets or in the absence of good quality historic data on mature assets, it is normally considered good practise to carry out a baseline survey to establish a known condition from which to monitor.

4.7 PLANNING

The next step in the planning cycle is to schedule the corrosion management activities. Corrosion management planning should be based on the corporate, long-term strategies and objectives for the production facility. Corrosion management is not a standalone process and therefore the scheduling of activities needs to be integrated with the operations and maintenance plans for any particular facility. It is common for both long term, circa 5 years, and short term, circa 12 months, plans to be developed. Final detailed scheduling of activities is often linked to more short term 60-90 day operations plans.

Planning can be divided into three main areas:

- **Work Planning**: The main functions of the work planning stage may include scheduling and integrating the inspection and monitoring activities within the overall asset strategy, and identifying the preferred deployment of inspection and monitoring resources and technology. This includes the development of work packs for campaigns of activities.
- **Resource Planning**: identification of both personnel and physical needs over identified time periods should be built into the implementation stage from the planning stage.
- **Methods and Procedures**: it is generally considered appropriate that the techniques and procedures to be used and followed during the implementation phase should be clearly identified. Written procedures are required for all aspects of implementation of the corrosion management plans in order to

ensure consistency in the data collection, definition of criteria on non-conformance and specification of clear lines of authority and reporting

During the planning stage the Key Performance Indicators/performance standards for asset corrosion management system should also be identified and agreed with the asset management team.

Example 17. Key Performance Indicators
– *Number of leaks per year*
– *Number of "near misses" per quarter*
– *Percentage of equipment scheduled for inspection that has been inspected per quarter*
– *Period between identifying repair requirements and implementation*
– *Number of unscheduled outages caused by corrosion damage*
– *Percentage of equipment identified as being within 2 years of retirement*

For the success of any monitoring scheme there are three points that need to be considered during the initial planning exercise regarding acceptable performance indicators, which is that they should be:

- Measurable
- Achievable
- Realistic

4.8 IMPLEMENTATION *

Management of the corrosion risks is achieved through a combination of proactive and reactive monitoring measures.

- ***Proactive*** measures are where the requirements and implementation of the monitoring system or inspection programme are identified and put in place before any corrosion or deterioration has been observed, based on either output of a Corrosion Risk Assessment or based on some other review/identification of areas of possible/likely corrosion.
- ***Reactive*** measures are implemented after a problem has been identified (either as a consequence of proactive monitoring or because of an incident or observation of a problem).

Proactive monitoring itself comprises of ***in-line*** and ***on-line*** systems these involve the collection of data, which enhances knowledge of the rate of corrosion degradation and allows steps to be taken which will prevent failure and ***off-line*** systems where techniques that retrospectively identify corrosion degradation and quantify the causes/onset, extent and degree to which it has occurred are employed.

* Note in this context *Implementation* means the monitoring/inspection process only, and not the implementation of corrosion control measures. This is covered under *Corrective Action*, see section 4.12.

Reactive monitoring will normally be limited to off-line systems, and are also normally aimed at quantifying the extent/distribution of any deterioration that has occurred.

Successful management of corrosion requires that cost-effective combinations of various mitigation procedures be employed to minimise risks to asset integrity, to control hydrocarbon releases and to ensure safety. The choice of corrosion control for any specific asset depends on factors such as fluid composition, pressures and temperatures, aqueous fluid corrosivity, facility age and technical culture of the organisation.

Corrosion inspection and monitoring are key activities in ensuring asset integrity and control of corrosion. Field data and the results of laboratory evaluations should be trended to obtain up-to-date corrosion information. Management decisions on equipment condition, prediction of remnant life and requirements for chemical treating are only as good as the information input provided from field experience. Corrosion inspection and monitoring includes assessment of:

- Operating environment, including changes in produced fluids compositions
- Metal wastage
- Pitting (including extent, depth and growth rate)
- Erosion and erosion corrosion
- Environmental cracking
- Fluid corrosivity assessments
- Development of biological activity.

In-line systems cover installation of devices directly into the process, but which need to be extracted for analysis, e.g. corrosion coupons, bio-studs, etc.

On-line monitoring techniques include deployment of corrosion monitoring devices either directly into the process or fixed permanently to the equipment, such as:

- Electrical Resistance (ER) probes
- Linear Polarisation Resistance (LPR) Probes
- Fixed ultra-sonic (UT) probes
- Acoustic Emission
- Monitoring of process conditions

Off-line monitoring is mainly achieved through the use of inspection and NDT techniques, which include:

- Visual
- Ultrasonics
- Radiography
- Pulse Eddy Current

The use of alternative methods of detection in the future should be considered in the light of any new findings recorded. New inspection and monitoring technologies should also be evaluated and considered as part of an ongoing system improvement process.

It is considered valuable that opportunity based visual inspections (OBVI's) should have a place in the overall corrosion management scheme. OBVI's occur when an opportunity is presented to perform a condition assessment of equipment as a result of production or maintenance outage or through production watch keeping and planned maintenance activities. The data from the opportunistic inspections should be fed into the inspection and corrosion databases to supplement the information gained during planned inspections.

Example 18. Opportunistic Inspection
Many operators are increasingly formalising the use of opportunistic inspection, during normal maintenance or production work. In these cases simple forms are developed to allow the maintenance staff to record the condition of components, including use of digital cameras. This records both presence and absence of corrosion. *In opportunistic inspection it is import than the maintenance crew have an awareness of corrosion issues (see Example 9) to ensure that the best information that can be obtained from this limited access is provided.*

Example 19. Corrosion Damage Reporting
Many operators incorporate Corrosion Damage Reporting (CDR) systems, where any corrosion observed is recorded in a standard format and reported back onshore for evaluation and inclusion in future planned campaigns if further detail is required. *Also, trend analysis on reports from associated equipment can identify a change in overall corrosion condition/inadequacy in current control systems.*

Whilst CDR is a reactive measure, OBVI can be considered both reactive and/or proactive. They can both provide a vital early warning of possible problem areas before the situation becomes significant.

Whether data is collected from planned or opportunity inspections, it is of immense value when awareness of corrosion issues is increased across the workforce as a whole. This ensures that at every available opportunity, areas where corrosion could be a problem are looked at. Similarly it is important that non-specialist staff understand that corrosion damage, which will always start small, can increase at an exponential rate if not checked in time.

4.9 DATA GATHERING & STORAGE

Information from corrosion management and inspection activities should be collated and gathered together to enable data assessment. This information should also include relevant process conditions and chemical inhibition data.

Data Gathering

Typically the data gathered will include:

- Process conditions, highlighting any changes
- Visual observations
- Corrosion monitoring data
    - Weight loss coupons,
    - Electrical resistance (ER) probes

    - Erosion/sand probes
    - Galvanic probes
    - Linear polarisation resistance (LPR) probes
    - Field signature method (FSM)
    - Fixed ultrasonic measurement systems
- Inspection data covering
    - Ultrasonic inspection data
    - Radiographic (x-ray) inspection data
    - Pulse Eddy Current (PEC) inspection data
- Known process escapes/leak statistics/corrosion damage reports

Not all inspection and monitoring systems are required/applicable for any particular facility and their use will be dependent on the type of corrosion process/material damage that is expected/being looked for. It is not intended that this document provides a detailed description of the different techniques which can be found elsewhere [12],[14],[15]. Further references can also be found in the bibliography.

Data Storage

During the planning and implementation stage careful consideration of data storage, data management and data analysis is required. Electronic data storage is considered beneficial by many operators for ease of data management, however, manual paper based systems are also used successfully, especially for smaller or mature assets. In either case careful consideration should be given to the upkeep of data, where and how it is stored, and who requires access to it. The latter point is particularly important where several different organisations are engaged in the corrosion management process.. Main points for consideration include:

- Data traceability and auditability should be considered.
- The asset operator should maintain overall control and responsibility for data and data storage, however, this does not necessarily mean a requirement for it to be located on the operator's facility.
- Computerised databases are not mandatory, although a formal, readily searched database of some recognised format is recommended.
- Common format computerised databases that will handle the all the different types of corrosion, inspection and process data are recommended, and can greatly assist data analysis.
- The ease of transferring data from contractor-to-operator and/or from contractor-to-contractor should be considered.

4.10 DATA ANALYSIS

The individual responsibility for data collation and data analysis should be clearly identified, and the reporting structure evident. The reporting period of corrosion data should be in keeping with the potential safety impact of the data assessed, and should be delivered on time.

Once the available information has been assessed, it may be combined with the data from the Corrosion Risk Assessment to perform a risk based analysis. The analysis should assess the potential for, and the consequences of, failure of items

[14] BP Amoco report ESR.95.ER.053; *Corrosion Monitoring Manual*; S Webster & R Woollam, November, 1996.

[15] NACE Technical Committee Report 3T199, *Techniques For Monitoring Corrosion & Related Parameters In Field Applications,* December, 1999

of equipment on the asset, with safety critical items being singled out for special attention.

Key features of the analysis of corrosion data are:

- The trends with period of operation
- The correlation of trends from different monitoring/inspection techniques
- The correlation of trends with operational parameters
- The prediction of remnant life
- Application of relevant statistical analysis to allow correct extrapolation of data to the whole structure/facility.

There are many uncertainties associated with corrosion monitoring and inspection data, resulting from natural limitations of techniques, variability of corrosion, human performance variables, etc. Statistical analysis of data can allow such variabilities of the data to be accommodated.

Example 20. Simple Development of Trend Information

If wall thickness data is obtained at the same location over a period of time a trend line can be determined and the remaining life of the component estimated from simple linear extrapolation to the minimal allowable thickness (MAT).

Many operators also calculate both the so-called "short corrosion rate" (calculated from the last two measurements) and "long corrosion rate" (calculated from the first and last measurements), if there is a significant difference between the two it indicates that the corrosion rate has changed within the last inspection period. A typical trend analysis for a single inspection point in shown in Figure 12 below

Location	160	**Tag**	V508		
Position	1	**Test Point / Keypoint**	VS1		
Circuit	CIR10R/34	**Date**	06-Jun-98		
Short Corrosion Rate	0.38	**Long Corrosion Rate**	0.57	**Design Corrosion Rate**	0.2
Remaining Life Operating Based	9.28	**Remaining Life Design Base**	6.65	**Design Life**	01-Jan-03
Installation Date	01-Jan-83	**Next Inspection Due Date**	18-Aug-99		

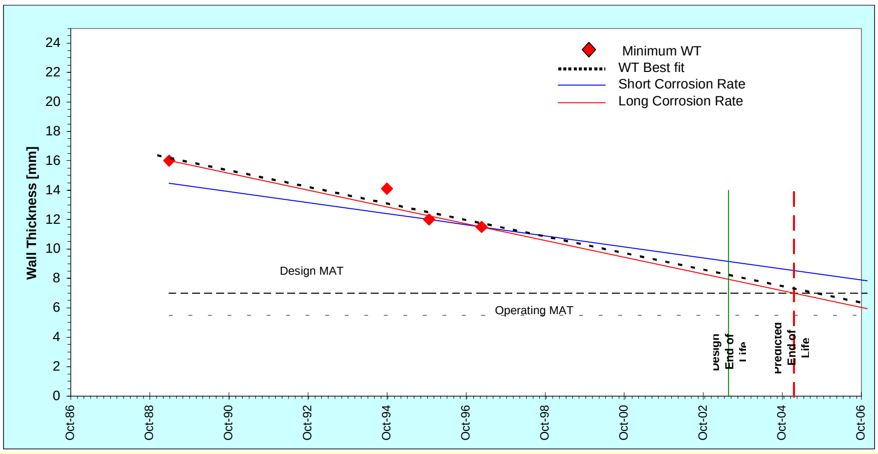

Figure 12 Example of simple trend analysis for individual inspection points.

Example 21. Confirmation of Extent of Deterioration by Statistical Methods

Where wall thickness measurements are not taken at the sample point a simple analysis (as in Example 20) is not possible. However, meaningful data analysis can still be obtained by using basic statistics.

For example a two separate inspections were carried out (18 months apart) on a production header, by two different inspection companies obtaining 21 readings in the first one survey and 26 readings in the second.. Whilst some of the readings may have been taken at nominally the same point, it was not possible to carry out a "like-for-like" *comparison, and originally it was concluded that the data therefore had no value.*

Simple statistical analysis based on comparison of the means showed that the ***average*** *wall thickness had reduced by 1.1 mm over the 18-month inspection period and that this change was statistically significant (at a 1% level of significance* [*]*).*

Example 22. Use of Advanced Statistical Analysis to Identify Corrosion Risk

Some operators and consultants are now using advanced statistical analysis, based on ***Extreme Value Statistics*** *(EVS) to optimise the results of inspection programmes. For corrosion inspection EVS provides a method for reliably extrapolating limited information, and can, for example, identify the likely largest pit (and even the size of the 2nd, 3rd, 4th largest pits etc) across a structure or facility.* [16]

The use of graphical displays/spread sheets is essential in assisting with the data interpretation to provide information for good corrosion management.

Consideration should also be given during the design of monitoring programmes and analysis/interpretation of data to the following points:

- Use of inspection data obtained during fabrication and pre-service testing can provide baseline information
- Comparison of regular/continuous in-line / on-line monitoring data with less frequent off-line inspections are needed to establish acceptable correlation for a particular production system
- Measurements from single points (UT/insert probes) should be treated as suspect unless confirmed by backup information from other sources
- Procedures should ensure that appropriate process data/information on water cuts/CO_2/H_2S contents is input into the corrosion data bank for later comparison with corrosion trends

Note that the main purpose of the corrosion allowance is to "buy time" to detect excessive metal loss and take preventative actions. Thus the total time to determine and report of out of compliance conditions includes the time required for the monitoring/inspection activities and the time to take corrective actions.

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* A *1% level of significance* implies that the chance of reaching a wrong conclusion is ≤ 1%

16 "*Extreme Value Statistics and its Relevance to Corrosion Engineering"*, D G John and P J Laycock, paper presented at UK CORROSION '92, Manchester, UK, pub. Institute of Corrosion, Leighton Buzzard, UK

This must be sufficient to carry out repairs/replacements or modify the corrosion control programme.

4.11 REPORTING

Anomaly reporting, responsibilities and procedures should be in place to ensure that, when anomalies are identified, they are reported in a timely manner and recommendations for their resolution are acted upon. The reporting structure for anomalies is particularly important where alliances are in place between the asset owner and one or more contractors. Positive acknowledgement of completion of actions is required in order to assure that the loop from anomaly reporting through to resolving the anomaly is completed. Relevant information and lessons learned should be fed back into the Corrosion Risk Assessment document. This is equally applicable both in the event that corrosion is found and when corrosion is not evident where it was anticipated.

The reporting format should be structured to ensure the key features and problems are clearly evident, along with actions to be achieved.

4.12 CORRECTIVE ACTION

Once the Corrosion Risk Assessment has been completed and/or corrosion monitoring and inspection data have been collected and analysed the necessary corrective action(s) required need to be identified and put into place. The options available will depend upon the type of facility and the nature/extent of the damage/deterioration identified.

For any system there are only six different options that can be considered.

Appropriate Materials	Options	C-Mn Steels, corrosion resistant alloys, non-metallics
	Locations	Pipework, vessels, tanks, valves. CRAs for lines/deadlegs that don't receive inhibitors
	Actions	Selection of appropriate material at construction/major refurbishment stage
Chemical Treatments	Options	Corrosion inhibitors, biocides, oxygen scavengers
	Locations	Pipework, vessels, tanks. Use selected packages in gas lines/water lines
	Actions	Batch/continuous dosing, package modification
Coatings & Linings	Options	Organic coatings, metallic coatings, linings, cladding
	Locations	Gas and liquid phases, internal & external
	Actions	Inspect during application, future inspection & repair schedule depends on duty
Cathodic Protection	Options	Sacrificial anodes, impressed current systems
	Locations	Vessels containing aqueous liquids, large bore pipework
	Actions	Need ability to monitor performance on-line
Process Control	Options	Identify key parameters, pH, water-cut, temp, pressure, dehydration
	Locations	Internals of vessels/pipework
	Actions	Dehydration of gas, control velocity/fluid shear stress, pressure reduction
Design Detailing	Options	Ensure ease of access/replacement
	Locations	Eliminate crevices, galvanic effects
	Actions	Stress raiser elimination, ensure smooth fluid flow

The practicality and economic impact of different options will also depend on the life cycle stage of the facility i.e. new build/major refurbishment or existing/ageing asset.

Highly corrosive environments and/or "sour" conditions (that is process fluids containing moderate to high levels of hydrogen sulphide), for example, may need special corrosion resistance alloys for specific engineering solutions as indicated in numerous industry guidelines, codes and standards (see Bibliography). However, application of newer technical developments for example use of specially designed corrosion inhibitors, can enable equipment to perform satisfactorily outside normally accepted operational windows, as described in some of the following examples.

It is not the intent of this document to identify all the different corrosion problems and the different options for control. Information on this subject can be found in the various publications listed in the bibliography. A few examples, however, are presented below which identify the wide range of options available.

Example 23. Separation Vessels - New & Existing

Some of the most critical components in offshore oil & gas production are the vessels used to separate gas, oil and water. In many cases the corrosion conditions are such that carbon manganese steels alone are not sufficient to ensure adequate operational life.

Various options are available to provide an acceptable life, which include use of internal coatings and lining, internal cathodic protection and use of corrosion resistant alloys. The selection of the most appropriate technique will be dependent on whether the corrosion problem is identified before fabrication or only after operation. In the later case internal cathodic protection can be used successfully to provide the necessary corrosion control for carbon steel vessels.

Example 24. Aggressive Service and Inhibitor Selection

Improvements in corrosion inhibitor performance under high velocity erosion-corrosion conditions may allow for carbon steels to be used instead of corrosion resistant alloys. This approach, however, is only effective when a specially selected inhibitor, usually injected at a high dose rate, is made available for virtually all of the operational period. That is >95% inhibitor efficiency and >95% inhibitor availability may well be required; a much more proactive management activity and difficult task to effect adequately unless properly organised and managed (see Example 25).

Example 25. Inhibitor Selection

An example of a good approach to assessments linked to inspection/ monitoring during both initial design or re-evaluation of a facility is described in "Corrosion Predictive Modelling" [17] and summarised in Tables 3 and 4. Although primarily developed for pipelines it may also be applied to production facilities fabricated from carbon steel.

Risk Category	***Maximum Required Inhibitor Availability***	***Max. Expected Uninihb. Corr. Rate (mm/yr)***	***Comment***	***Proposed Category Name***
1	*0%*	*0.4*	*Benign fluids, corrosion inhibitor use not anticipated. Predicted metal loss accommodated by corrosion allowance.*	*Benign*
2	*50%*	*0.7*	*Corrosion inhibitor probably required but with expected corrosion rates there will be time to review the need for inhibition based on inspection data.*	*Low*
3	*90%*	*3*	*Corrosion inhibition required for majority of field life but inhibitor facilities need not be available from day one.*	*Medium*
4	*95%*	*6*	*High reliance on inhibition for operational lifetime. Inhibitor facilities must be available from day one to ensure success.*	*High*
5	*>95%*	*>6*	*Carbon steel and inhibition is unlikely to provide integrity for full field life. Select corrosion resistant materials or plan for repairs and replacements.*	*Un-acceptable*

Table 3. Corrosion Inhibitor Risk Categories

[17] "*Corrosion Predictive Modelling*", A.J. McMahon & D.M.E. Paisley, Sunbury Report, ESR.96.ER.066, November, 1997.

Example 25 cont.

Corrosion Inhibition Risk	***Overall System Requirements***	***Inhibitor Injection System***	***First Inspection Schedule***	***Monitoring of Subsea lines***
Category 1	*Does not rely on corrosion inhibition.*	*No requirement*	*Routine inspection as determined by previous operation of similar systems.*	*Process monitoring of fluids.* *Standard inspection techniques at accessible points.*
Category 2	*Inhibition may not be used in early life but must be available when conditions change, i.e. increased water cuts*	*Commissioning without shutdown*	*As category 1*	*As category 1 plus weight loss coupons, ER / LPR probes and occasional intelligent pig runs.*
Category 3	*Inhibition not available due to logistics problems but must be operated as soon as possible.*	*Commissioned as soon as practical and incorporate level device and flow monitor into injection system.*	*Early inspection as determined by anticipated corrosion rates.*	*As category 2 plus FSM or UT mats system. Continual logging for all monitoring devices.*
Category 4	*Corrosion control must be working on day one. Inhibitor and dose rate pre-selected*	*As category 3*	*As category 3*	*As category 3 plus increased inspection frequency.*
Category 5	*Assumes all technical, environmental and financial factors have been answered satisfactorily. Requirements as category 4*	*As category 3*	*As category 3*	*As category 4* *(Note that for on-shore pipeline facilities a leak detection system would be also installed)*

Table 4. Summary of Monitoring & Inspection Requirements

Example 26. Corrosion Under Insulation (CUI)

In one facility a problem had been identified with CUI of high temperature pipework. The insulation was regularly wetted with seawater.

It was determined that the insulation was in place for protection of personnel, (i.e. to prevent accidental burning from touching the hot pipework) rather than for any process requirement.

The solution adopted was to remove the insulation and, where appropriate, place an open 'grating' around the pipework to prevent accidental contact

Example 27. Process Modification

A real example of what can go wrong with Process Modifications, occurred on an aging production system where, due to increasing water cut it, was decided to change the system from a 3-way separation (i.e. oil, water and gas) to a 2-way separation (i.e. oil-water emulsion and gas) process. This resulted in oil-water emulsion passing through pipework that had been originally manufactured in carbon steel, on the basis that essentially only dry oil would be present.

The change in process had been made without reference to corrosion/ materials engineers and without reference to the original design assumptions used in the material selection.

Significant corrosion was subsequently found in the pipework down stream of the separators and upstream of the corrosion inhibitor injection point

The solution finally adopted was to move the inhibitor injection point to immediately down stream of the separators and to increase the inhibitor dosage significantly.

In all cases the overall driver is for ongoing improvement in corrosion control by continuous review and analysis of performance.

5. MONITORING AND MEASURING PERFORMANCE

5.1 PURPOSE

This section will outline the way in which performance standards or Key Performance Indicators are used to monitor and measure the extent (or otherwise) to which policy objectives are being met by Corrosion Management Systems.

It should be noted that this section covers the monitoring and measurement of performance of the corrosion management system itself, and not the monitoring and measurement of corrosion (which is covered in section 4.8).

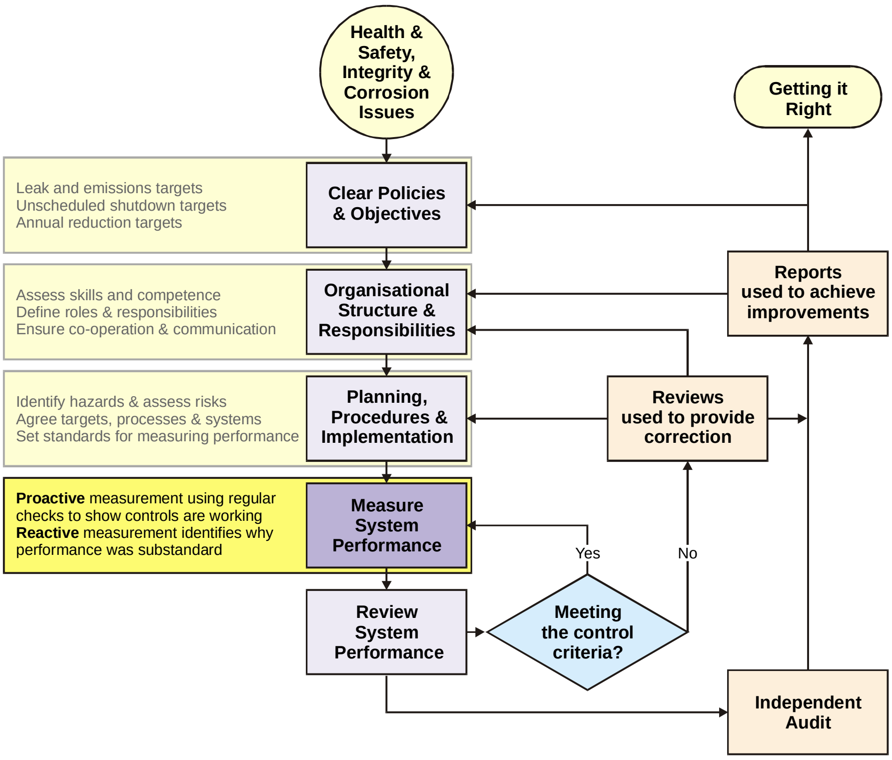

Figure 13 Performance Measurement to Demonstrate a Working System

5.2 SCOPE

The checks & balances within the Planning & Implementation process ensure the performance of, for instance, particular monitoring techniques or inspection regimes is as expected. The methodology described in the following section stands at one remove from this, taking as a given that the accuracy of techniques and the competence of individuals, and covers the monitoring and measurements of the level of success attained in achieving pre-set standards or indicators.

The process of Performance Measurement includes consideration of

- Setting Performance Measures
- Responsibility
- Frequency
- Monitoring of Performance
- Measuring Performance
- Corrective Actions

5.3 RESPONSIBILITY

Because this activity relates to the review of the management process itself, the responsibility for overseeing the process of measuring performance should lie with suitably competent individuals who are, ideally, appropriately free of production pressures.

Similarly the measurement of performance tasks should lie with personnel outside those directly responsible for implementation of the specific procedures and processes being assessed. The process should involve discussion with, and feedback to, each relevant business unit manager and personnel in that unit responsible for the various aspects of implementation and control of the processes and procedures.

This separation of responsibility for implementing corrosion management, corrosion monitoring or corrosion control from the task of measuring the overall performance of these processes is vital to avoid potential conflict of interest.

Areas of responsibility include:

- Performance standards; under the control and review of the individuals responsible for the activity and/or the integrity engineer.
- Pressure Vessels (PVs), Pressure Safety Values (PSVs), associated pipework and valves, inspection; under the control of facilities engineering / maintenance
- Number of release incidents, impact on the environment; under the control of the manager responsible for Safety, Health and Environment (SHE) issues.

5.4 FREQUENCY

The frequency of the measurement of performance may vary for any operator and for different business units/assets within an organisation. For example, the performance for individual assets may be routinely assessed on a 3-month or 6-month basis, whilst the performance of the operation as a whole may only be re-measured on an annual or bi-annual basis.

The frequency of measurement chosen will depend on the extent to which data demonstrates historical reliability/stability.

As Performance Measurement covers all aspects of the processes, procedures and management, a series of different levels of measurement, each with differing appropriate frequencies, should be developed. A number of activities require immediate review/measurement on completion of a task. This would include, for example:

- Review process at end of the Corrosion Risk Assessment (CRA). The measurement/review may take the form of cross checking of assumptions/ historical data and trends and would take place immediately after the completion of the CRA.
- Monthly review of Corrosion Damage Reports (CDR) and/or Opportunity Based Visual Inspection (OBVI) information.
- Assessment of actual execution of inspection & monitoring work is in accordance with requirements / standards.
- Quarterly review of effectiveness of corrosion control matrices.

The frequency of measurement required will also depend upon the particular assets and processes under review. In circumstances where relevant historical data and experience of operation using the same procedures and processes is available and has been subject to review and where changes will not be made during the relevant period, then longer periods before measurement of performance can be justified. In circumstances where new processes or procedures have been implemented, more frequent mesaurement is essential. This may be relaxed subject to effective implementation and proof of adequacy.

Procedures would normally be set up to ensure that any incident results in review of the processes and procedures, and that preventative modifications are implemented wherever appropriate.

5.5 SETTING PERFORMANCE MEASURES

Measurements to assess attainment of pre-determined performance criteria can be set for various indicators, these should include consideration of:

- Number of leaks
- Proportion of hydrocarbon releases
- Number of other accidents and incidents
- Number of unplanned business interruptions
- Non compliance of management systems
- Appraisal of the management system
- Monitoring the performance of groups or individuals within the system
- Acceptable metal loss per year
- Performance of physical inspection techniques used to assess asset condition
- Progress of risk based inspection and maintenance activities compared with initial expected outcome
- Achievement of inhibitor availability criteria
- Performance of corrosion monitoring techniques employed for inhibitor control
- Trends – showing no significant problems to end of field life

Each of the above should have quantified targets set during the development of the risk assessment and management system and as a consequence of any subsequent review. Initial measurement, therefore, needs simple comparison of the quantifiable factors to ensure that targets are met.

5.6 PROACTIVE AND REACTIVE MEASUREMENT OF PERFORMANCE

Only by regular measurement can it be demonstrated that the corrosion policies and corrosion control procedures are effective.

Two types of measurement system are used:

- Proactive Measurement
- Reactive Measurement

Proactive Measurement of Performance

Proactive measurement:

- Uses regular checks and inspections, or even continuous evaluations, to ensure that agreed criteria are being met
- Makes measurements before things go wrong
- Predicts when a system is not working, monitors the condition and, by means of feed-back reporting and control procedures, prevents damage
- Measures success and reinforces positive achievement by rewarding good work
- Should not penalise failure

Proactive measurement involves the comparison of targets and achievements covering the areas described in 5.5.

Reactive Measurement of Performance

Reactive measurement involves the review of actions taken in the event of incidents and review of possible changes to reduce further the probability of incidents.

Reactive measurement involves:

- Reviewing of "after failure" activity
- Repair incidents
- Other evidence of deficient corrosion control performance, including cases of unacceptable damage or near misses
- Mal-operation
- Unexpected events
- Inadequate procedures

Measurements of performance, both proactive and reactive, should be subject to a periodic review procedure.

In general Measuring Performance does not include the identification of the cause of incidents but rather ensures that the procedures and processes result in appropriate response to the incidents including identification of cause. However, it is important that any underlying causes (be they changes in process conditions or in adequacies in the corrosion management system) are identified.

6. REVIEW PERFORMANCE

6.1 PURPOSE

This section details the review process by which duty holders/operators ensure that the Corrosion Management Procedures and Processes are consistent with the changing business plan and changing production requirements.

It should be noted that by Review of Performance refers to the normal in-house review of the overall corrosion management system and does not cover the detailed review of corrosion monitoring / corrosion inspection data (which is covered in sections 4.9 and 4.10) or any formal audit of the system (which is covered in Section 7).

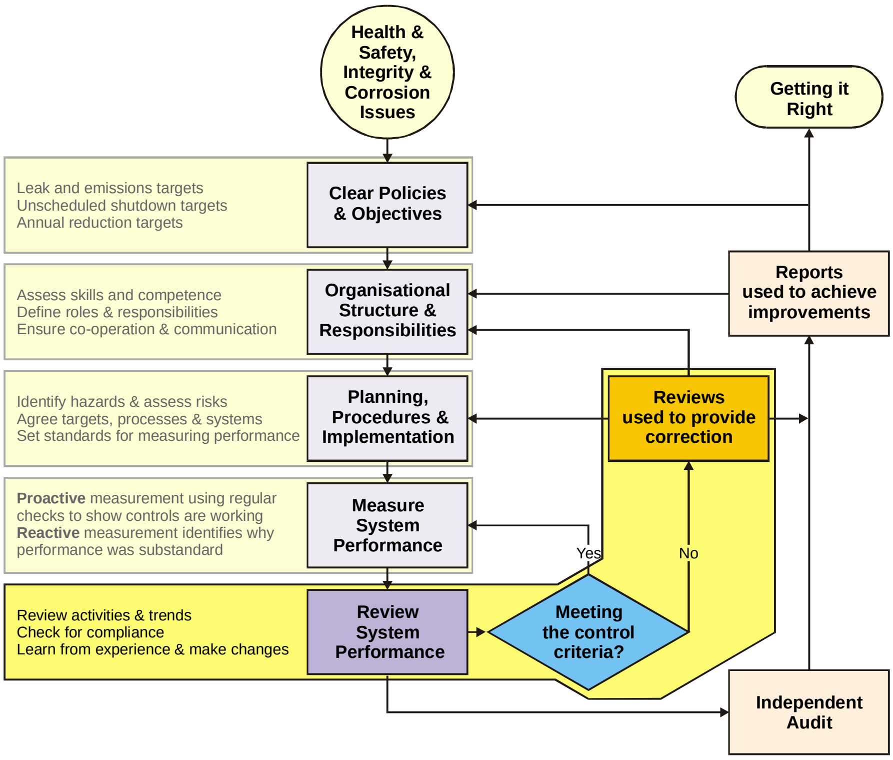

Figure 14. Review Performance, Meet Agreed Criteria or Ensure Change

6.2 SCOPE

The scope of the system review will include all aspects of the procedures and processes. As with performance measurement it too requires both reactive and proactive approaches.

The system review includes:

- Assessment of the effectiveness of the processes and procedures in terms of improving SHE, for example, reducing the number of emissions, reducing the number of incidents, improving conformance to schedules and improving procedures to minimise escalation of incidents and to ensure that feedback is effective in improving performance and reducing incidents.

- Ensuring that the procedures and processes in place will not be compromised by planned changes arising from the business plan and by changing production requirements.
- Carry out review of measured parameters covering both proactive and re-active measures (as per Section 5 and Example 28).

Example 28. Typical proactive and reactive measurement for system performance

Typical proactive measurements would include:

- *Assessments of the corrosion management system*
- *Reporting of "out-of-condition"*
- *Response to requests, evaluation of feedback*
- *Control of process conditions*
- *Dosage of chemical treatments*

Typical reactive measurement would include:

- *Incidents, Accidents and Emissions*
  - *How was the incident identified?*
  - *What immediate action was taken to prevent escalation, minimise emission?*
  - *What actions were taken to identify the cause(s) of the incident?*
  - *Were the causes properly identified?*
  - *Have procedures and processes been reviewed appropriately and modified to prevent recurrence?*
  - *Have the procedures and processes been implemented?*
- *Delay in Implementation of Schedules*
  - *How was the delay identified?*
  - *Has the cause of the delay been properly identified?*
  - *Have procedures and processes been amended to prevent recurrence of delays?*
  - *What was the possible impact of the delay in implementation of the scheduled activity?*
  - *Has the potential impact of the delay been addressed?*
  - *Have procedures and processes been reviewed appropriately and modified to prevent recurrence?*
  - *Have the procedures and processes been implemented?*

6.3 FREQUENCY

The frequency of review will depend upon the particular nature of the assets and processes involved and the circumstances prevailing at the time. It is common practice to carry out an initial review one year after implementation of a Corrosion Management System. The period to the next review should be addressed at each review. The period will be dependent upon whether frequent and/or significant changes in demand/process are likely to influence the adequacy of the corrosion management system.

The Corrosion Management System itself should incorporate processes and procedures to ensure that any such changes are highlighted and their potential influence addressed promptly. Performance Reviews ensure that agreed criteria are being achieved. This means that processes and procedures are in place and operating correctly, that required targets are achieved and that procedures have been appropriate for the relevant period and will remain appropriate at least until the next planned Review of Performance.

In addition, trends should be reviewed to provide any necessary correction and improvements:

- Ensure that information generated as a consequence of incidents, for example, and the associated changes to procedures and processes are being incorporated into company wide instructions and are being implemented properly by all businesses/assets.
- Determine whether particular areas/businesses/assets are performing better or worse than average in terms of achieving Key Point Indicators (KPIs) and in reducing incidents. The causes of any divergence should be investigated and fed back through the organisation to further enhance control and safety.

In the event that the business plan/process requirements change during a review period this should itself lead to review of the system. There should be a procedure in place to review the potential impact on the Corrosion Management System and to ensure that modifications to procedures and that processes are developed, tested and implemented before those changes take place.

This does not mean that every change to production requirement results in review and modification of the system. This only applies to changes outside those encompassed in the previous business plan.

6.4 CORRECTIVE ACTION [*]

Substandard performance should be investigated and reported if improvements are to be made and mistakes eliminated. The use of standard forms will aid the reporting of the monitoring results. However, the use of appropriate procedures and a suitable data base, which allows easy access for investigation and analysis, and for development of a response system for problem reviews and action is essential.

Where key point indicators have not been achieved it is important that the cause(s) are identified and that any necessary measures to ensure that the system can be improved are implemented. It is the constant re-examination and incorporation of lessons learnt that lead to improvement of the corrosion management system. This is covered in the central task within the overall management system as expanded in **Error! Reference source not found.** (next page).

[*] *Corrective Action* in this context refers to changes required to the corrosion management system itself, and not to repairs to equipment or modifications to corrosion control programme, which are covered in section 4.12

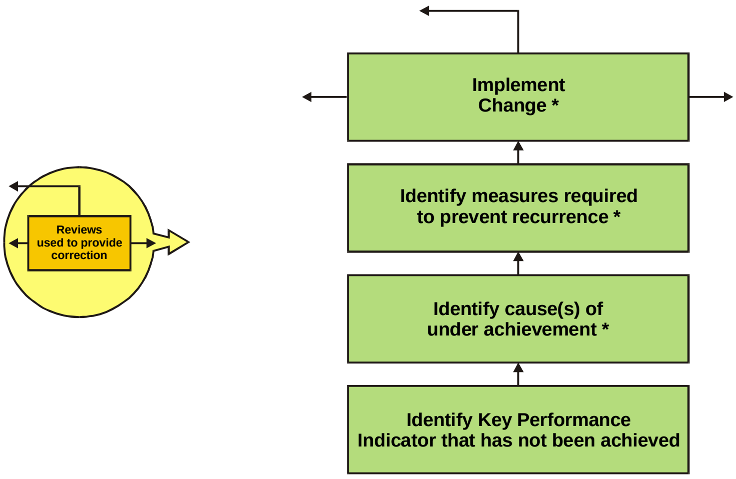

Figure 15 Continuous Improvement by Measurement of Performance*

Both the proactive and reactive measurement systems require supporting procedures that not only investigate causes of substandard performance but also recommend improvements in procedures. The essentials from a management control audit are not only the technical (rates of corrosion/remnant life) issues but also the procedures, organisational structures and individual responsibilities (the management systems) that also require verification.

6.5 REVIEW PROCEDURES

Where changes are required to be made prior to the next scheduled review which are outside of the anticipated conditions identified at the previous review, then a review should be undertaken immediately and before those changes are made. This review will:

- Identify which assets/units will be effected
- Identify the changes that will take place
- Feed back the changes to the relevant departments/businesses/responsible individuals for:
  - Assessment of potential impact
  - Identification of changes required to processes and procedures
- Ensure that appropriate changes are made to processes and procedures and that they are implemented.

It is important that no changes to production as a consequence of changes to the business plan are implemented until the above steps have been completed, either at a scheduled review or at a special review arising due to the required changes.

Another aspect that should be considered in the review process is to consider any lessons learnt from incidents on other installations and industries, e.g. onshore petrochemical.

* These areas would normally involve discussion with, and feedback to, the relevant business unit/department

7. AUDITS

7.1 PURPOSE

The following section details the process of audit of the corrosion management system. The purpose of the audits it to ensure that the Corrosion Management System is efficient, effective and reliable, and that the processes and procedures are being implemented in accordance with the procedures. Safety Case Regulations (SCR) require the duty holder's management system to ensure that adequate arrangements are established for audit report making.

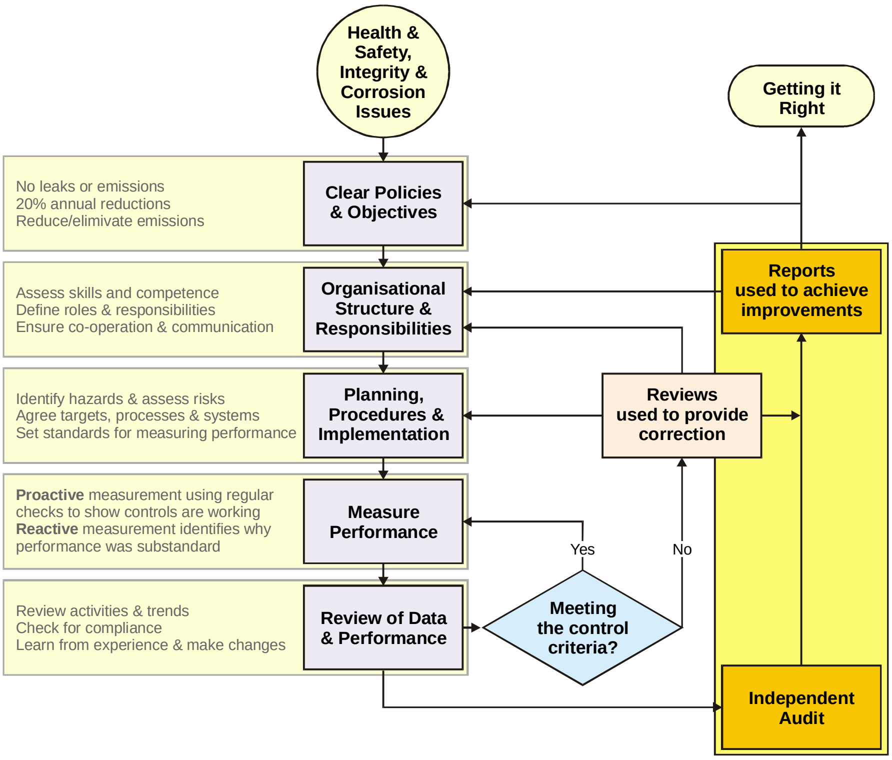

Figure 16. Independent Audit Scheme that Ensures Improvement

7.2 SCOPE

Audits are an essential check on the performance of the corrosion management system and will normally be carried out by an independent party. In principle the audit would include determination of management processes employed to ensure continuing integrity and the condition of equipment. The audits cover all aspects of:

- Implementation of procedures and processes
- Competency
- Checks in place
- Compliance

The audit does not cover aspects such as achievement of Key Performance Indicators, but that the processes and procedures aimed at achieving those targets, and the procedures for ensuring that they are being achieved are being properly implemented. Where activities are not in accordance with the procedures and processes they will be identified as being non-compliant.

In addition to these audits, more frequent internal audits will be carried out covering specific procedures and/or specific units or functions. Contractors' procedures will be audited on award of contract if not covered by pre-qualification.

7.3. RESPONSIBILITY

Audits should be carried out by persons sufficiently independent to ensure that their assessment is objective. In most instances, audits will be carried out by independent organisations on behalf of the duty holder/ operator. The duty holder/operator will be responsible for ensuring that appropriate remedial action is taken. This process will ensure that the audit cannot be closed out until all actions are cleared. Audits may be carried out by either an external third party organisations or by an in-house, but independent, consultancy group. In all cases it is important that the auditors are not directly involved in the day-to-day operation of the corrosion management system.

The more frequent audits relating to specific aspects of the assets or functions can be carried out by in-house personnel provided they are appropriately independent of production.

7.4. CURRENT BEST PRACTICE

The success of audits depends on the implementation and maintenance of a fully auditable structured framework including clearly defined responsibilities and roles.

Audits should be carried out by competent persons. Where outside organisations are employed for independent audits, the individuals should be appropriately competent.

The audits will include review of procedures, review of records and discussions with relevant company personnel. Audit reports should include progress results and recommendations.

Highlights from the annual audit report and all in-house audits should be disseminated to all relevant personnel. Details of the in-house audits and findings should be made available to the independent auditing body prior to the annual audit.

Wherever practicable, checklists should be developed for specific processes/installations in order to ensure consistency of audits and to ensure appropriately comprehensive cover.

Example 29. Checks to ensure that procedures and processes are being complied with include

- *Review of documentation and records to assess conformance*

- *Review of records of non conformances and incidents to ensure that*
  - Appropriate investigation was undertaken in accordance with the procedures
  - Any investigation was effective and that any necessary changes to procedures and processes to prevent recurrence have been developed
  - Changes have been incorporated into the procedures and processes
  - Changes are being implemented

- *Tracking of specific procedures and processes to ensure compliance including competency of responsible individuals, departments and organisations and including correct implementation, reporting and reaction.*

- *Wherever non compliances are identified, this should result in the following programme:*
  - Investigation of cause(s)
  - Assessment of changes to procedures/processes to prevent recurrence
  - Implementation of changes

- *When a non compliance is identified, the audit should not be closed out until the appropriate changes have been implemented*

An example of an audit checklist is given in Appendix B. This example covers all the different aspects of a corrosion management system as described in this document, by its very nature not all of the different tasks will be applicable to individual assets.

One aspect that has been identified by several organisations is that the results of audits of corrosion management systems are often not as well documented as may be implied by the above examples. This is often because the corrosion management system audit is carried out as part of a general audit of an organisations operation. For the most benefit to be gained it is important that the results, and in particular the recommendations and list of corrective actions identified in the audit, are recorded with the corrosion management system

8. CONCLUSIONS ON FRAMEWORK METHODOLOGY

A corrosion management system has been outlined that provides a general and progressive framework that is compatible with the requirements of an offshore safety management system concerned with ensuring the integrity of topside processing equipment. That is, employers should have effective plans and organisations to control, monitor and review preventative and protective measures to secure the health and safety of persons.

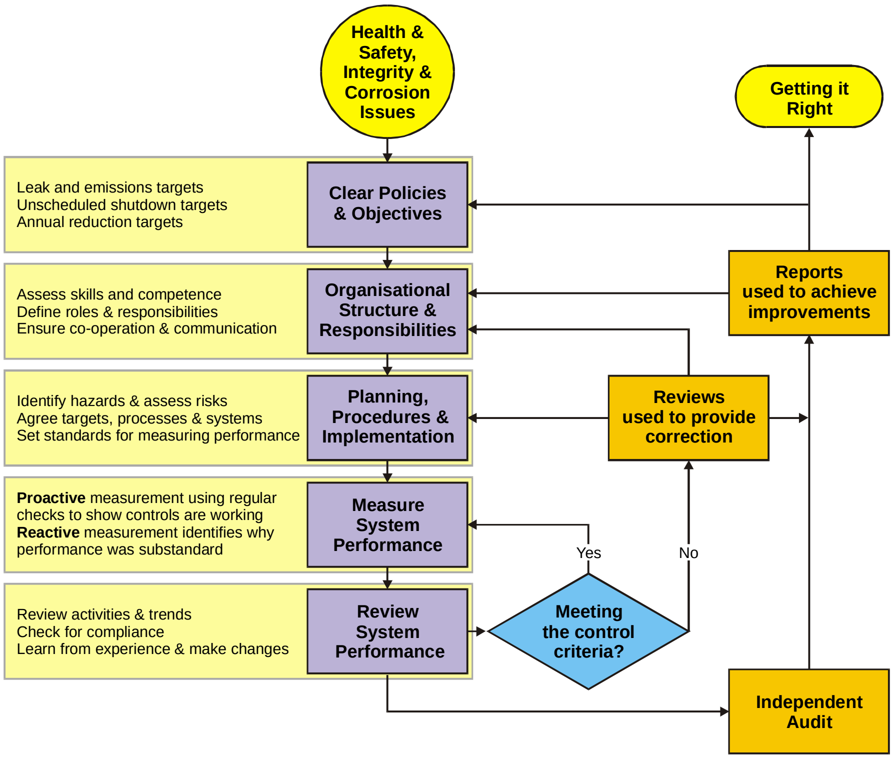

Figure 17. Basic Corrosion Management Process to Ensure Safe Operation

Such a system, as shown in **Figure 17** can operate at various managerial and technical levels within an organisation. The degree of complexity will depend on both the size of the operation - the number of personnel, the roles and responsibilities of managers, engineers, technical support staff and contractors. The system will also have technical input in terms of risk assessments for safety-critical items and control systems such as availability of chemical treatment, corrosion inspection and corrosion monitoring, which in turn is determined by the materials of construction (corrosion resistant alloy versus carbon-steel), the fluid corrosivity, water cuts, age of the production system and maintenance strategies adopted.

Practical experience from the North Sea has shown that the development of comprehensive corrosion management systems, coupled with a commitment by both the operator, maintenance contractor and specialists sub-contractors / consultants, can lead to a major improvement in the operation of offshore topside processes. Experience has also shown that the corrosion management system works best, in fact can only work, when it is a *live document* and is used and revised on a regular basis.

APPENDIX A.

EXAMPLES OF RISK CONTROL SYSTEMS AND ASSOCIATED ACTIVITY ASSESSMENTS

Sections 2 to 7 of this document identified the key elements that form the framework methodology for corrosion and integrity management. Development of the framework for a particular facility requires the application of risk control systems and activity assessments as indicated in Section 1.6.

Organisations frequently have layered structures of various functional groups, each with identifiable objectives and responsibilities. Each group can be considered as a self-contained Risk Control System where the processes adopted by the group to achieve the required goals reflect the allocated responsibility for risk.

Various managerial and engineering levels, as well as key processes and procedures may be identified for assessment as specific risk control systems, viz.:

- Senior Management Involvement
- Asset Managers and Senior Engineers
- Management of Contractors
- Hazard Analysis and Risk Assessment
- Information and Records
- Verification
- Operations (Routine and Non routine
- Inspection and Maintenance
- Accident and Incident Investigations
- Emergency Response
- Personnel and Training

Each risk control system will have an input, process and output which together with their associated activities should be the subject of an assessment to evaluate the degree of risk to the overall corrosion and integrity management system.

These three basic stages are:

- The input into the group/activity
- The processing or actions undertaken
- The output or measured performance

From a health and safety view point the objective is to eliminate hazards and risks by means of clearly defined Risk Control Systems for each level of responsibility or activity. The complexity of any specific Risk Control System would depend on the responsibilities/activities involved and the performance standards that would be developed and agreed. Responsibilities and objectives will devolve from corporate level through asset management to managers with direct control over specific project decisions, installations and operations.

Input Stage

At the input stage the performance standards should cover information such as group membership (design, construction, operation, inspection, maintenance, specialist contractor) and the technical activity (design process, standards and guidance, selection and installation of equipment, operation and maintenance to agreed criteria).

Process Stage

The internal activity stage (or process stage) would involve assessment of technical risks associated with processing equipment, as well as those risks created where people interact with their jobs (e.g. not having the necessary information or backup, overlooking an important piece of information, failure to report non-compliance or carry out corrective actions, etc.).

- The aim is to minimise such risks and consequences by use of a proactive approach, rather than reliance on an "after the event" or reactive management culture.
- Performance standards should be available, along with clearly defined responsibilities, methods and routes for dissemination of information and receipt and handling of information, as well as specification of procedures, for example; the operation of the system, safe use of equipment, planned changes, contingency planning, decommissioning activities, etc.

Output Stage

The output stage objectives are to minimise risks external and internal to the organisation and groups, including those from work activities, products and services.

Activity Assessments

A vital element of corrosion management is to identify key activities within each 'self-contained' Risk Control System. The thoroughness of the activity assessment should be proportionate to the particular hazards and risks.

Typical processes are:

- Hazard identification
  - anything that can cause harm, including actions/no actions
- Risk assessment
  - examination of what could cause harm
  - evaluate the degree of risk, high/low
- Risk control
  - eliminate risks by modification of the system
  - combat risks at source by engineering/management controls
  - minimise risk through suitable control measures

The activity processes involves:

- Simple check lists/questions
- Reviews at agreed hold points in a project
- More complex and detailed procedures, viz HAZOP studies, criticality or formal engineering risk evaluations.

Identification of hazards and assessing risks is fundamental for any management process.

- A hazard has the potential to cause harm or damage
- Risk is the combination of the severity of the effect (the consequences) and the likelihood of it happening (damage mode and probable frequency).

Industrial risk assessment is a careful examination of potential hazards that may affect the operation of a business; these may be risks associated with the safety and integrity of physical assets, risks to the environment, financial risks from various decisions and also risks from corrosion or inadequate corrosion mitigation procedures. At its simplest, risk assessment is a common sense approach that provides a means of checking what is often good existing practice.

FMECA

Typical of the risk-based procedures is the Failure Mode, Effect and Criticality Analysis (FMECA) that ranks perceived risks in order of seriousness:

Criticality (**Risk**) = Effect (**Consequences**) × Mode (**Probable Frequency**)

Failure Criticality - potential failures are examined to predict the severity of each failure effect in terms of safety, decreased performance, total loss of function and environmental hazards.

Failure Effect - potential failures assessed to determine probable effects on process performance and the effects of components on each other.

Failure Mode - anticipated operational conditions used to identify most probable failure modes, the damage mechanisms and likely locations.

The analysis determines the probability of each failure mode occurring (P), the seriousness (consequences) of the failure (S) and may also include the difficulty of detecting the failure (D). The criticality index (C) provides a numerical ranking (C = P × S × D) that enables management to focus on procedures (appropriate maintenance and corrosion control strategies, including inspection activities) on items of plant, or processes, that are deemed to have either high/unacceptable risks or low/acceptable risks.

Design and Construction Phase

Input	***Process***	***Output***
Senior management involvement	*Define the Corporate Safety, Health and Environmental Policies and include Process Equipment Integrity & Corrosion policy* *Set goals and objectives for the design brief, include integrity & corrosion* *Approve high level management systems, including quality system processes and corrosion management* *Allocate resources and define responsibilities to meet goals.* *Ensure review and auditing procedures are in place.* *Ensure complacence with polices*	*Produce written company statements, include consideration developing business plans and goals* *Integrity commitment. Collect independent information on system effectiveness.* *Written guidance in business plan and its details. Develop corrosion control system in parallel with design.* *Use independent verification scheme as required of a duty holder.* *Allocate ultimate accountability and responsibility to named individual* *Appoint independent verifier*
Input	***Process***	***Output***
Design Engineers and Construction Managers	*Check that policies/strategies are in place during the design process and fabrication stage that will ensure corrosion safe operation processes and equipment integrity.* *Agree establishment of roles, who is responsible for what and who is accountable.* *Ensure that appropriate strategies & systems are developed and implemented to review the following:- design concept, materials selection, O&M philosophies, corrosion mitigation, life cycle implications feedback from previous experience.*	*Written documentation that identifies the design goals on materials of construction, corrosion control and equipment integrity, these should indicate requirements for corrosion safe management practice.* *Agreement on core teams, named individuals with defined authority and lines of communication.* *Check that corrosion control meets project requirements, the design can accommodate upset conditions, that manuals and work books are produced that incorporate the requirements of the safety case and corrosion safe practice.*

(Design and Construction Phase cont.)

Input	Process	Output
Specialists and Contractors (Corrosion Engineers, Inspection and Materials)	*Development and use of systems for Design / Construction procedures and basic Operations & Maintenance (routine and non-routine).* *Address materials selection/ procurement/fabrication/testing procedures, check corrosion mitigation (chemical treating, coatings and cathodic protection) to identify impact of non-compliance on corrosion safe operation,* *Develop corrosion safe procedures for future O&M activities, Assess Inspection and Quality Assurance & Quality Control measures, Provide for verification and audit of systems, Define requirements of performance standards and methods to review performance.*	*Control of all activities related to the development of corrosion safe operation & maintenance with minimum hydrocarbon releases. What to do and what not to do.* *Provide actions for incorporation into construction and commissioning plans.* *Ensure that management systems are in place and in operation to provide good corrosion management practice. These should ensure that the equipment meets the design specifications, that the facility can operate in a safe manner, that previous experience of best practice is built into the procedures, the management system is subject to regular review and that all processes are auditable.*
Input	***Process***	***Output***
Hazard analysis and risk assessment	*Systems to be in place to identify sources of risk and hazards for operational equipment, to include deterioration mechanisms, assessment of likely rate(s) of deterioration, evaluate consequences, develop risk and manageability matrix, consider out of condition operations.* *Assessments carried out by competent persons.* *Procedures to define criteria for updating the risk assessments.*	*Define overall scope, check on key areas (process streams, items, i.e. manageable groups). Use check lists as in HAZOP studies, agree probability rate measures, agree consequences, ensure continuous update of assessment output for all life cycle phases (current and future).* *Decide on core team and leader, technical specialists and experience.* *Clear definition of risk acceptance criteria. Clearly documented decisions.*
Input	***Process***	***Output***
Information, Records & Database systems	*Identify and develop suitable database systems.* *Systems to control drawings and technical information.* *Listing of all information on hazards and risks to processing equipment.* *Applicable regulations, standards and codes of practice to be available.* *Records on integrity, operational limits, structural analyses.* *Information required by statute, safety case, verification records, etc.*	*Identify key areas for initial operational inspection.* *Rapid access for emergency purposes.* *Access available to all appropriate personnel and emergency services.* *Technical information relative to the construction, operation and maintenance.* *Technical asset history data base.* *Operational workbook.*
Input	***Process***	***Output***
Personnel and training	*Development of appropriate job specifications.* *Systems to select competent personnel.*	*Written guidance on requirements.* *Development of on the job training.*

Operations & Maintenance Phase

Input	*Process*	*Output*
Senior management involvement	*Define the Corporate Safety, Health and Environmental Policies (include Process Equipment Integrity & Corrosion)* *Set goals and objectives for the operation, include integrity & corrosion* *Approve high level management systems, including quality system processes and corrosion management* *Allocate resources and define responsibilities to meet goals.* *Ensure review and auditing procedures are in place.* *Ensure compliance with legislation.*	*Produce written company statements, include consideration developing business plans and goals* *Integrity commitment. Collect independent information on system effectiveness.* *Written guidance in business plan and its details. Ensure safety case and corrosion control systems are in place.* *Use independent verification scheme as required of a duty holder.* *Allocate ultimate accountability and responsibility to named individual* *Appoint independent verifier*
Input	***Process***	***Output***
Asset Managers and Senior Engineers	*Ensure policies are in place to ensure corrosion safe operation and equipment integrity (goals and objectives).* *Ensure that an integrated corrosion control programme is in place to implement the agreed corrosion management strategy.* *Agree establishment of roles and key players, who is responsible for what and who is accountable.* *Ensure that appropriate strategies & systems are developed and implemented.*	*Written documentation on corrosion. Management, inspection, integrity and maintenance strategies.* *Check that the corrosion control programme is integrated to operational and technical disciplines that affect the life of the asset.* *Defined agreement on named individuals and lines of communication (role and activity matrices).* *Production of O&M manuals and work books that encompass the management of corrosion risks.*
Input	***Process***	***Output***
Specialists, Support Units, and Contractors (Corrosion Engineers, Inspection and Materials Specialists)	*Development and use of systems for control of the corrosion mitigation programme, including corrosion inspection and monitoring; where appropriate this would include operations & maintenance (routine and non-routine),* *Ensure that corrosion control becomes an integrated activity within the day to day operations.* *Verification and audit of systems, including Emergency response, Asset integrity and Corrosion management.*	*Control of all activities related to corrosion safe operation, inspection programmes, maintenance and repair to ensure that hydrocarbon releases are minimised and the equipment is operated and maintained in a corrosion safe manner.* *Clarify the ownership issue, who is responsible and who has authority, and how does this impact on O&M issues.* *Legislative requirement for safety critical items, identify firm dates for revisions, peer review process.*
Input	***Process***	***Output***
Hazard analysis and risk assessment	*Use of criticality / corrosion risk assessment models to identify processes and activities of high risk* *Systems to be in place to identify sources of hazards and corrosion risk for operational equipment, processes and systems.* *Assessments carried out by competent persons.* *Procedures to define criteria for updating the risk assessments.*	*Information for the development of corrosion mitigation and risk based inspection activities.* *Continuous update of assessment output when conditions change, check that required measurements can be conducted and anomalies detected.* *Appoint appropriate team and identified leader.* *Clear definition of risk acceptance criteria. Clearly documented decisions.*

(Operation and Maintenance Phase cont.)

Input	***Process***	***Output***
Corrosion control systems and management programmes	*Define key operational parameters for corrosion mitigation by chemical treating, ensure that process keeps within design limits, define the chemical management strategy, include laboratory analysis.* *Review of performance, these will include the corrosion management and inspection system, the maintenance / repair records and the corrosion control / mitigation programme, usage of chemicals, inhibitor availability* *Develop corrosion monitoring and inspection as part of the integrated plant inspection and corrosion management programme.* *Ensure short term and longer term feed back of information for management control actions.* *Define analysis and reporting techniques, feedback routes linked to roles and responsibilities.*	*Ensure key parameters are clearly stated in Roles and Activity Matrices, for excursions, management of chemicals, maintenance of dosage equipment, engineering changes and repairs.* *Develop regular reviews of corrosion control measures, compliance (weekly / monthly), erosion / corrosion in key systems, repairs, anomalies (monthly / quarterly), Sign off of inspection reports (quarterly), Review of systems (annually).* *Define on-line and off-line monitors and instrumentation using baseline requirements, identify data to be collected, validated, analysed, trended and stored.* *Data management must relate to defined and agreed performance measurements (actual compared to expected).* *Ensure reporting results in appropriate actions for corrosion control.*
Input	***Process***	***Output***
Information, Records & Database systems	*Check that corrosion inspection data provides estimates of remnant life and indicates plant integrity.* *Checks that monitoring data conforms to predetermined criteria and is consistent with any available inspection and process data* *Identify develop and use suitable database systems.* *Checking on systems used to control drawings and technical information.* *Checks on listing of all information on hazards and risks to processing equipment.* *Checks records on integrity, operational limits, structural analyses, operational history, inspection programmes.* *Checks information required by statute, safety case, verification records, etc*	*Comparisons of required / design life with actual predicted life and recommendations for actions if required.* *Record, in a readily accessible format, any trends, anomalies / non-conformances that could effect future operation, integrity and maintenance.* *Identify key areas for trending of data from construction, start-up and initial operational inspection.* *Ensure rapid access, especially for emergency purposes.* *Ensure access available to all appropriate personnel and emergency services.* *Ensure technical information relative to the construction, operation and maintenance is in asset history data base.* *Ensure operational workbook is up todate and contains relevant information on all required activities..*
Input	***Process***	***Output***
Maintenance & inspection systems	*Continuous development and use of maintenance and inspection strategies that are proactive*	*Ensure planned maintenance and inspection procedures are carried out*
Input	***Process***	***Output***
Personnel and training	*Regular review and development of appropriate job specifications.* *Regular review of systems to select competent personnel.*	*Provide written guidance on requirements, including corrosion awareness.* *Setting up and incorporating on the job training programmes.*

APPENDIX B.

SAMPLE CHECKLIST FOR ASSESSMENT OF CORROSION MANAGEMENT SYSTEM FOR OFFSHORE PROCESSING FACILITIES

The sample checklist provided here has been compiled from a number of different checklist used by operators, contractors and specialist sub-contractors / consultants.

The checklist covers all the different areas of the corrosion management system as described in the main document, and covers:

- *Corrosion Policy*
- *Corrosion Strategy*
- *Assessment of Corrosion Risks*
- *Organisation & Personnel*
- *Planning & Implementation*
- *Data Management and Analysis*
- *Reporting*
- *Measuring Performance*
- *Evaluation of Performance*
- *Auditing*

It should be emphasised that this checklist covers all the different aspects of corrosion management system and as such the entire checklist will not be applicable to individual assets.

The checklist is intended to be used by both auditors to confirm that the corrosion management system is being properly implemented and by individuals / organisations in setting up corrosion management systems to ensure that all the necessary actions and tasks are incorporated.

CORROSION MANAGEMENT SYSTEM AUDIT						
Date		*Asset(s):*		*By:*		
Item	*Question*			*Yes*	*Not Used*	*Comments*
1.0 CORROSION POLICY						***See Chapter 2***
1.1	*Is there a company policy for corrosion management?*					
1.2	*Does it clearly state objectives for corrosion control?*					
1.3	*Does it define measurable performance targets?*					
1.4	*Does the policy demonstrate management commitment to corrosion control?*					
1.5	*Is there evidence of an awareness of this policy at all levels within the organisation?* • *Senior Management?* • *Engineers & Technicians?* • *Offshore staff?*					
1.6	*Are the personnel committed to the policy?*					
1.7	*Are review periods for the corrosion strategy specified?*					
2.0 CORROSION STRATEGY						***See Chapter 2***
2.1	*Is there a documented corrosion strategy for the asset?*					
2.2	*Does it place responsibility for corrosion control with a group or named individual within the organisation?*					
2.3	*Does the corrosion strategy interface with:* • *Safety Case?* • *Performance Standards?* • *Verification Scheme?* • *Maintenance Strategy?* • *Operations Strategy?*					
2.4	*Does the strategy state which items of plant are included and excluded from its scope?*					
3.0 ASSESSMENT OF CORROSION RISKS						***See Chapter 3***
3.1	*Is a formal Corrosion Risk Assessment (CRA) method used?*					
3.2	*Does this drive the mitigation, monitoring, and inspection activities?*					
3.3	*Does it assess the likelihood/rate of deterioration?*					
3.4	*Are all likely methods of corrosion deterioration considered?*					
3.5	*Do these consider the safety consequences from corrosion threats?*					

3.6	*Does it use any of the following as inputs?* • *Safety Policy?* • *Environmental Policy?* • *Legislative Requirements?* • *Asset Business Plan?* • *Design Conditions?* • *Current Operating Conditions?*			
3.7	*Are the results from historic operational corrosion monitoring used?*			
3.8	*Does this include cross asset/other operator experience?*			
3.9	*Are the operating conditions against which the CRA is carried out clearly stated?*			
3.10	*Does the CRA consider process excursions out with the normal operating case?*			
3.11	*Does the CRA consider future operational scenarios or "what if" cases?*			
3.12	*Are appropriate methods of detection for the expected deterioration methods documented?*			
3.13	*Does a cross discipline peer group review the CRA results?*			
3.14	*Is the CRA Maintained "live"?*			
3.15	*Is the CRA subject to periodic review?*			
3.16	*Are the initiating factors for a review documented?*			
4.0 ORGANISATION & PERSONNEL				***See Chapter 3***
4.1	*Is the organisation chart for corrosion management fully documented?*			
4.2	*Does this include any contractors used in corrosion management?*			
4.3	*Does it reflect current organisation?*			
4.4	*Are sufficient resources available to implement the corrosion strategy?*			
4.5	*Are roles and responsibilities for individuals clearly defined and documented within the strategy?*			
4.6	*Are authorities and reporting routes clear and documented?*			
4.7	*Are interfaces with other parts of the organisation visible?*			
4.8	*Have gaps and overlaps in responsibility been identified and eliminated?*			
4.9	*Are the procedures in place to assess the competency of staff assigned to corrosion management activities?*			
4.10	*Does this extend to measures of competency at all stages in the process?*			
4.11	*Is training on corrosion awareness given to non-specialist personnel?* • *Onshore?* • *Offshore?*			

5.0 PLANNING & IMPLEMENTING				***See Chapter 4***
5.1	*Are inspection programmes developed using a Risk Based Inspection Methodology?*			
5.2	*Does this relate inspection periods to a prediction of deterioration?*			
5.3	*Are activity plans included within the corrosion strategy?*			
5.4	*Does this include:* • *Long Term (circa 5 year) plan?* • *Short Term (circa 12 months) plan?*			
5.5	*Are plans integrated with:* • *Maintenance planning?* • *Operations planning?*			
5.6	*Is on-line corrosion monitoring devices used?*			
5.7	*Are locations for corrosion monitoring and inspection clearly identified within the work packs?*			
5.8	*Are suitable arrangements in place to monitor inaccessible areas?*			
5.9	*Are appropriate methods of detection for the expected deterioration methods documented which indicates appropriate corrosion monitoring devices and inspection techniques?*			
5.10	*Are the limitations of the applied corrosion monitoring and inspection techniques known?*			
5.11	*Do the work packs include procedures for the use of relevant inspection techniques?*			
5.12	*Do the work packs include criteria of non-conformance?*			
5.13	*If a non-conformance is identified does the work pack define the reporting procedures?*			
5.14	*Do these define time scales for action?*			
5.15	*Are opportunity reporting systems used out with planned activities?*			
5.16	*Do the Planned Maintenance Routines include opportunity inspection reporting?*			
6.0 DATA MANAGEMENT & ANALYSIS				***See Chapter 4***
6.1	*Is the data to be gathered for corrosion management requirements clearly defined?*			
6.2	*Are appropriate techniques for gathering the required data used?*			
6.3	*Is it clear who should receive and evaluate this data?*			
6.4	*Are procedures in place to validate the gathered data?*			
6.5	*Is the location where the corrosion monitoring & inspection data stored defined?*			
6.6	*Can historic data be easily retrieved?*			
6.7	*Are there database systems used for storage of corrosion monitoring data?*			

6.8	*Is process conditions, inspection, corrosion monitoring & chemical data collected and evaluated centrally?*			
6.9	*Is consideration given to the limitations of the inspection and monitoring techniques given during evaluation of data?*			
6.10	*Does the analysis of data consider short and long-term implications for corrosion control?*			
6.11	*Are investigations conducted to identify the underlying cause of corrosion incidents?*			
7.0 REPORTING				***See Chapter 4***
7.1	*Are the reporting routes clearly defined within the corrosion strategy?*			
7.2	*Is information dissemination within the organisation effective?*			
7.3	*Are the recipients of different levels of reports defined?*			
7.4	*Are systems in place to share corrosion knowledge internally within the organisation?*			
7.5	*Are arrangements in place to communicate corrosion incident experience externally?*			
7.6	*Does operational experience get fed back into design?*			
8.0 MONITORING & MEASURING PERFORMANCE				***See Chapter 5***
8.1	*Are measures of the success of the corrosion management activities in place?*			
8.2	*Do these measure performance against objectives set in the policy or strategy?*			
8.3	*Are Key Performance Indicators (KPI's) used?*			
8.4	*Are the performance measures meaningful and practical?*			
8.5	*Is information on performance widely available?*			
8.6	*Are records of loss of containment maintained?* • *Hydrocarbon releases?* • *Non hydrocarbon releases*			
8.7	*Are targets set for follow up actions to be closed out?*			
8.8	*Are measures in place to record the cost of corrosion including direct and indirect costs?*			
9.0 EVALUATION OF PERFORMANCE				***See Chapter 6***
9.1	*Are the Corrosion Management activities subject to a formal review?*			
9.2	*Are reviews carried out at a specified period and is this documented?*			
9.3	*Does the reviews include all parties in the corrosion management process and is this documented?*			
9.4	*Does the review involve key contractors?*			
9.5	*Does the distribution of the findings include senior management?*			

9.6	*Are actions as a result of the review implemented within a specified timeframe?*			
9.7	*Does the review evaluate any benefits to be gained from introducing new techniques or technology?*			
9.8	*Does the review feedback into the corrosion strategy?*			
10.0 AUDITING				***See Chapter 7***
10.1	*Are the Corrosion Management activities audited:* • *Internally?* • *Externally?*			
10.2	*Are records of audits maintained?*			
10.3	*Is there an identified party to ensure recommendations are implemented?*			
10.4	*Are contractors in the corrosion management process audited?*			

APPENDIX C.
GLOSSARY OF TERMS AND ABBREVIATIONS

API	American Petroleum Institute
ASNT	American Society of Non-Destructive Testing
ASTM	American Society for Testing and Materials
CDR	Corrosion Damage Report
CRA	Corrosion Risk Assessment
CSWIP	Certification Scheme for Weldment Inspection Personnel
DCR	Offshore Installations And Wells (Design And Construction, Etc) Regulations 1996 (SI 1996/913)
DNV	Det Norsk Veritas
EEMUA	Engineering Equipment and Materials Users Association
EFC	European Federation of Corrosion
ER	Electrical Resistance
EVS	Extreme Value Statistics
HSW	Health And Safety At Work Etc Act 1974
ICORR	Institute of Corrosion
KPI	Key Performance Indicators
LPR	Linear Polarisation Resistance
MAT	Minimum Allowable wall Thickness
MHSWR	Management Of Health And Safety At Work Regulations 1992
NACE	National Association of Corrosion Engineers
OBVI	Opportunistic Based Visual Inspection
PEC	Pulse Eddy Current
PCN	Personnel Certification in Non-Destructive Testing
PFEER	Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (SI 1995/743))
PV	Pressure Vessels
PSV	Pressure Safety Valves
RBI	Risk Based Inspection
RCS	Risk Control Systems
SCR	Offshore Installations (Safety Case) Regulations (Si 1992/2885)
SHE	Safety, Health & Environment
TQM	Total Quality Management
UKCS	United Kingdom Continental Shelf
UT	Ultra-sonic Thickness measurement

Hazard	That which has the potential to cause harm or damage
In-line Monitoring	Refers to installation of monitoring equipment directly in the bulk of the process, but data acquisition requires extraction of probes or process shut down for analysis, e.g. corrosion coupons, bio-studs, etc
Intrusive Monitoring	Requires penetration through the pipe or vessel wall to gain access to the interior of the equipment
Non-intrusive monitoring	Monitoring from the outside of the pipe or vessel without having to gain access to the interior of the equipment
Off-line Monitoring / Inspection	Refers to measurements carried out on the equipment intermittently, for example analysis of liquid samples, non-intrusive inspection (e.g. UT, PEC, radiography, etc)
On-line Monitoring / Inspection	Refers to installation of monitoring equipment for continuous measurement of metal loss, corrosion rate or other parameters in an operating system. Data are obtained without the requirement to remove the monitoring device, e.g. LPR probes, ER probes, fixed ultrasonic transducers, etc
Proactive	To investigate / review an item without any prior requirement. Use to predict events rather than to react to them
Reactive	To investigate / review an item following an incident or some other factor which prompts the investigation.
Risk	The combination of the severity of the effect (the consequences) and the likelihood of it happening (damage mode and probable frequency).

APPENDIX D.
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