PLANT INTEGRITY MANAGEMENT

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As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 190, *Plant Integrity Management*. This publication was jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

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Amendments from 190/14

Section	Change
	Editorial to align style with IHC associations
All	Rearrangement and complete re-write as part of IHC harmonisation

Note Technical changes from the previous edition are underlined

1 Introduction

This publication has been prepared by industrial gas companies to establish a common position and give guidance on plant integrity management. This topic is also referred to as plant ageing and is increasingly included in authority inspections of plants subject to regulations such as Directive 2012/18/EU *on the control of major-accident hazards involving dangerous substances* (Seveso III Directive) and Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) in Title 29 of the U.S. *Code of Federal Regulations*, etc. [1, 2].[1]

Ageing is not about the age of the equipment. It is about its condition and how that changes over time. Ageing is the effect whereby equipment suffers some form of material deterioration and damage (usually, but not necessarily, associated with time in service) with an increasing likelihood of failure over the lifetime. For more information, see HSE RR823, *Plant Ageing Study – Phase 1 Report* and HSE RR823 Summary Report, *Managing Ageing Plant—A Summary Guide* [3, 4].

The integrity of equipment can be ensured by:

- operation of the equipment within design conditions;
- documented programme of procedures, training, inspections, tests; and
- preventive/predictive maintenance including inspection based upon good engineering practice, applicable codes, standards, specifications, and manufacturers' recommendations.

It is important to recognise that equipment can be subject to ageing, can contribute to the health, safety, and environmental performance of a plant, and / or can compromise the performance if they fail or collapse. Therefore, a broad view is required when assessing the potential impact of ageing at a given installation.

2 Scope and purpose

2.1 Scope

This publication gives general guidance on integrity management of process plants including, but not limited to, air separation plants, HYCO plants, cylinder filling plants, and carbon dioxide, acetylene, and nitrous oxide plants. The goal is to keep hazardous fluids and energy contained in order to maintain safe working conditions for personnel and prevent unacceptable environmental releases. The information contained in this publication applies to both new and existing equipment. Integrity management starts when the equipment is first put into service and continues throughout its lifecycle.

This includes:

- piping;
- static and rotating equipment;
- equipment civil structures and foundations;
- electrical, control, and instrumentation equipment;
- pressure vessels; and
- combinations thereof.

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[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

The user is cautioned that this publication is not a design handbook and does not exclude the need for competent engineering judgement and interpretation. To the extent that they exist, national laws may supersede the information included in this publication.

2.2 Purpose

The purpose of this publication is to give guidance on plant integrity management to operations management within the industrial gases industry to ensure the safety of equipment. The industrial gases industry has fewer damage mechanisms than the general process industry. This publication identifies damage mechanisms specific to the industrial gases industry, explains the basis for them, and provides guidance on how to develop an integrity management programme. This publication does not give guidance on plant reliability or efficiency.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Ageing

Effect whereby a component or equipment suffers some form of material deterioration and damage usually, but not necessarily, associated with the time in service with an increasing likelihood of failure over its lifetime.

3.2.2 Competent person(s)

Individual or a group of people who have the theoretical knowledge, practical experience, and training to identify design defects, to detect defects, to assess their importance, and to ultimately endorse equipment as fit for continued service.

NOTE In some countries, regulations require that the final endorsement be carried out by a notified body / competent authority / accredited organisation.

3.2.3 Formal periodic inspection plan

Defines what inspections shall be carried out, when, by whom, and how the results should be reported.

3.2.4 Process plants

Assembly of process equipment and piping including their primary protection devices; electrical, control, and instrumentation equipment; and equipment civil structures and foundations.

4 Plant integrity management programme

4.1 General

For more information, see EEMUA 231, *The mechanical integrity of plant containing hazardous substances—A guide to periodic examination and testing*; HSE RR509, *Plant Ageing: Management of Equipment Containing Hazardous Fluids or Pressure*; and Center for Chemical Process Safety (CCPS), *Dealing with Aging Process Facilities and Infrastructure* [5, 6, 7].

Successful management of plant integrity requires a clear strategy not just for periodic inspection, but for the whole lifecycle of the plant. This is especially important on sites storing and processing hazardous substances, where the effects of integrity failure can have serious consequences.

The requirements for inspection may change throughout the equipment life. In the early stages, it may be necessary to ensure that a whole range of issues potentially arising from the design, manufacture, and first exposure to service conditions are addressed. It can also be required to test assumptions on active degradation mechanisms or verify predicted rates. This can lead to relatively shorter intervals between inspections, compared to later stages of its life.

With further service, degradation can begin to accumulate. Safety margins such as remaining corrosion allowance or remaining fatigue life can decrease. Degradation rates can increase and overall confidence in the mechanical integrity can decrease. Service periods between inspections may be reduced. For more information, see HSE RR509 [6].

While this publication focuses on inspection and how to define rules for inspection, it is very useful to put this into context as this is only one element of an integrity management programme. The design of a plant can impact the integrity management programme. Getting the original plant specification correct is key so the plant is designed to be suitable for the intended duty.

Key to maintaining integrity is the assessment of the results of inspections, especially when the report states that the equipment has defects.

Any integrity management system should be able to provide answers to the following questions:

- What pressure systems and equipment storing, processing, or transferring hazardous substances are on site;
- Who is responsible for these pressure systems and equipment;
- What considerations are given to equipment ageing and life extension;
- What company strategies or policies are in place for managing ageing;
- What records / documentation about the equipment are maintained;
- Can your company demonstrate it has the competencies required;
- What provisions are in place for the retention and use of corporate knowledge;
- Does the plant/equipment have a retirement date;
- How well is the equipment life cycle known;
- How aware is your company of the indicators of ageing;

- Does the approach to inspection take account of the stage of equipment life;
- What options are considered when ageing related damage is detected;
- How is fitness for service assessed for aged components and components where the remaining life is uncertain;
- What procedures are used in the event that equipment requires repair;
- What procedures are in place regarding revalidation of equipment;
- Does the formal periodic inspection plan reflect the equipment's age; and
- What policies are in place for determining the end of equipment life.

4.2 Organisational arrangements for integrity management

A thorough, organised, and unified integrity management program provides the means to improve the safety of process plants. Such a programme provides the information for operations management to allocate resources for prevention, detection, and mitigation actions that can result in improved safety and a reduction in the number of incidents. An integrity management programme requires a multidisciplinary approach with a range of different disciplines and competencies bringing the required information and controlling the whole process from planning and execution through to decision making and review.

4.2.1 Competence

Those responsible for managing and undertaking maintenance, testing, and inspection shall be competent. Someone with an appropriate engineering qualification and relevant experience should manage the maintenance, inspection, and testing systems and arrangements.

Inspection bodies shall be able to demonstrate competence.

Non-destructive examination (NDE) personnel shall be able to demonstrate training and competence. Official certification can be achieved under either an outside body certification or an employer-based scheme.

In addition to the formal arrangements for qualification and accreditation described previously, an effective plant integrity management program requires consideration of all aspects of the potential degradation, inspection, and assessment of the equipment involved. Therefore, the team involved requires competency to provide input in the following areas:

- design of the equipment;
- process conditions and potential consequences of a loss of containment;
- operating conditions;
- maintenance;
- materials technology (including corrosion or metallurgy expertise, where relevant);
- risk assessment; and
- inspection techniques.

The use of third parties in equipment integrity management shall have checks in place to confirm the competency of those parties involved. These shall include competence checks as part of the selection and monitoring processes for contractors. Where in-house resources are used, it is equally important that there are means to ensure the competence of those involved.

4.2.2 Roles and responsibilities

The clarification of roles and responsibilities is required to ensure that the different parties involved in a plant integrity management program interact effectively, and each role is filled by competent persons and regulatory requirements are met. Arrangements shall ensure independence of the inspection body from the site operating and supply requirements.

The responsibility for assessment of the integrity of the plant and / or equipment shall be clearly defined. This assessment is required to determine fitness for continued service and may involve specification of conditions for continued service or repair.

It is important to ensure that whoever is responsible for integrity assessment is able to undertake this task without undue influence from other parts of the organisation that can have other potentially conflicting responsibilities or priorities. Furthermore, those in ultimate authority for the site or company operations should be able to demonstrate a commitment to equipment integrity by providing the necessary independence to those they charge with making key decisions regarding fitness for service.

Operations management shall ensure the plant is maintained in a safe condition. While site operations management can seek to rely on third party expertise to help ensure equipment integrity, they should be aware that the responsibilities cannot be delegated.

4.3 Technical arrangements for integrity management

The integrity management program shall include the following elements:

- data gathering;
- risk assessment;
- inspection plan;
- inspection; and
- post assessment.

Figure 1 shows an overview of an integrity management work process. Elements of this process may vary on a case-by-case basis (for example, individual equipment, multiple pieces of similar equipment, or generic equipment classes across multiple plants).

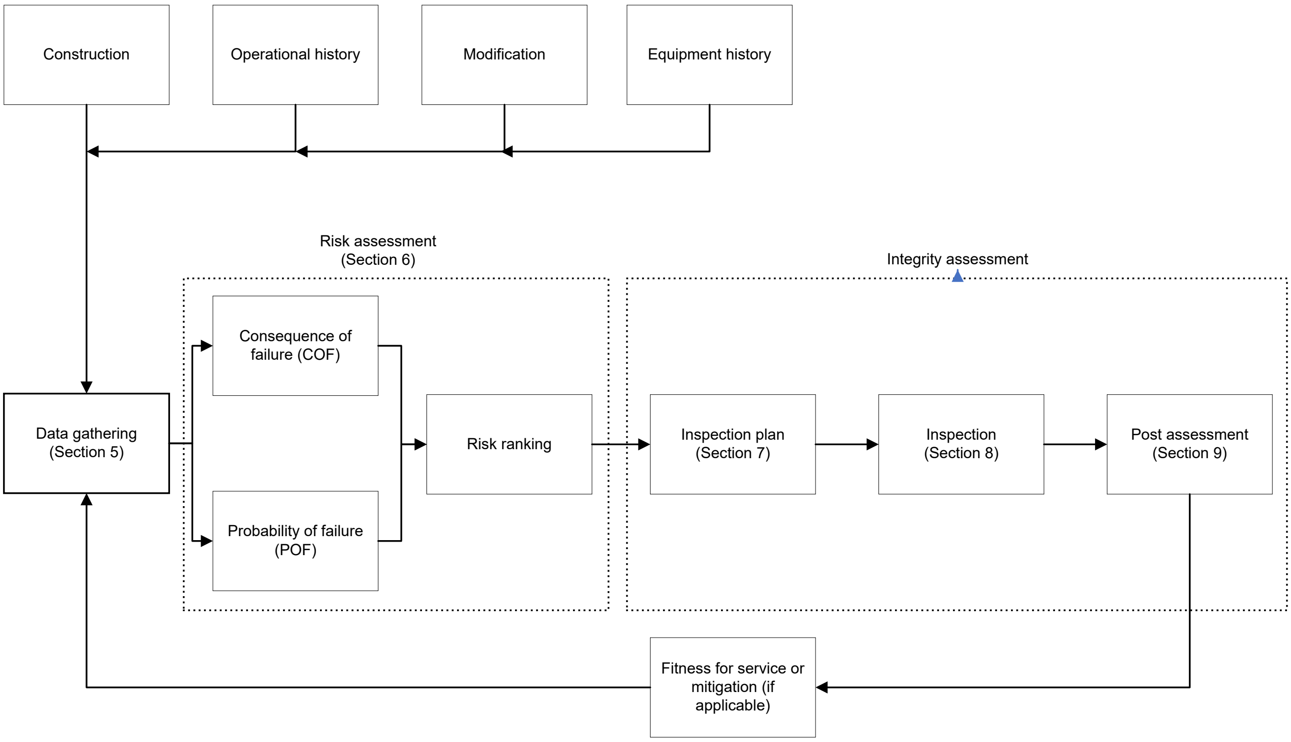

Figure 1 – Integrity management work process

5 Data gathering

Data shall be gathered and should be maintained for the life of the plant. This data can build up a written history and can reveal ongoing problems / failure modes. The amount and quality of data can improve the validity of the integrity management program. Data can include, but are not limited to, records for:

- design and construction;
- baseline inspections (first inspection performed based on damage mechanisms);
- operational history (for example, process upset, operational excursions);
- maintenance (planned and reactive);
- weather and ambient conditions;
- inspection and assessment;
- damage and repair;
- modification;
- equipment failures and malfunctions; and
- preventative and mitigation measures.

Data may also be collected for plants and equipment other than those that are being assessed.

A data management system such as a database should be used for the management of data.

6 Risk assessment

Risk is typically described as the product of two primary factors. The probability of failure (PoF) and the resulting consequences of the failure (CoF). For more information, see ISO 31000, *Risk management—Guidelines* [8]. Risk assessments serve to organise data and information and to help prioritise and plan activities as well as to determine which inspection, prevention, and / or mitigation activities are performed and when.

For each piece of included equipment, the failure mechanism(s) shall be identified considering the substances and processes contained within the equipment and their effects on the materials of construction. See Section 13. A risk assessment based on the relevant degradation mechanism(s) shall be performed and the results used to develop an inspection methodology and frequency for each piece of included equipment. The inspection strategy for a piece of equipment can be a mixture of activities to address equipment integrity issues (i.e., safety and environmental concerns) and maintenance investments to promote reliable and efficient operations. Not all loss of containment events for industrial gas processes are equipment integrity issues. The nature of the fluid (pressure, temperature, composition) and location of the equipment relative to individuals that can be impacted by a loss of containment event are all important considerations for determining whether a loss of containment event should be considered an equipment integrity issue.

6.1 Operational excursions and fitness for service assessment

Operating conditions should not differ from the operating range originally considered for the design without a management of change (MOC) process [9]. However, operational excursions where the actual operating conditions exceed those for which the equipment was designed can cause permanent damage.

Where an operational excursion has occurred, operations management should consult with a competent person and jointly agree if a fitness for service assessment is required. This assessment is outside the normal schedule of inspections as specified in the inspection programme and is designed to detect and assess whether or not the equipment has been damaged as a result of the excursion.

6.2 Modifications

There may be times during the life of the plant when it needs to be modified. The driver for this may be a desired process change or in response to revised best practice or regulation for that industry. Whatever the driver, the modification shall be subject to a MOC process, including appropriate risk assessments [9]. If there is a modification, the risk assessment shall be reviewed to determine if any changes are required.

7 Inspection plan

The inspection plan is an essential part of an integrity management programme. It is used to define what inspections and tests shall be carried out, how often, by whom, and how the results should be reported. It also specifies what preparatory work shall be undertaken to allow the inspection to proceed. Therefore, it is important that the plan is carefully worded and is prepared by one or more competent person with an extensive and detailed knowledge of the equipment and the processes contained within the plant.

The aim of an inspection is to ensure that the equipment is fit for continued service. However, the specific objectives of any inspection or test may vary; therefore, it is important to be clear about what an inspection is intended to achieve.

It is important to complete an inspection before equipment is put into service for the first time:.

- Initial inspection (pre-commissioning) – This inspection is normally carried out before plant or equipment is entered into service for the first time and ensures that the equipment has been designed and manufactured in accordance with all the relevant drawings and specifications. This is used to assist in the establishment of the initial integrity of the plant/equipment and also allows for material thickness measurements to be taken before any deterioration has taken place; and

- First inspection (post commissioning) – This inspection establishes a baseline and provides an early opportunity to identify any issues with the design, manufacture, or installation once the plant/equipment has entered into service. The benefit of this inspection is greatest if the period between commissioning and the first in-service inspection is minimised before possible degradation mechanisms can create significant damage and provides the most value for plant processes that are unfamiliar to operations management.

Local, regional, or national regulations covering the inspection of equipment shall be followed.

The industrial gases industry generally does not carry out periodic inspection of cryogenic equipment within a coldbox or cryogenic bulk storage tanks. See Appendices A and B for more information.

7.1 Selection of inspection types

Inspection types shall be selected to monitor for damage from known degradation mechanisms. Additional inspections may be selected to identify or account for unexpected mechanisms. This may include a combination of special inspections and periodic inspections.

There is a range of inspection options available. These include simple checks to complex inspections. The value of the inspection is a function of the applicable potential degradation mechanisms, the frequency of inspection, and the effectiveness of inspection.

The exact nature of the inspection type to be used is a matter for consideration in formulating the formal periodic inspection plan. Inspection types include:

- Internal inspection – An inspection of the interior of the equipment. This type of inspection requires access to the internal components and surfaces of equipment. Certain equipment can be difficult and costly to prepare for internal access. There can also be confined space issues to consider and whether an inspector entering the equipment presents a risk. If alternative non-invasive techniques are to be considered, the alternative inspection techniques shall be evaluated to determine whether they have equivalent capability of detecting the degradation mechanisms as internal inspection;

- External inspection – An inspection undertaken from the exterior only. This type of inspection examines the equipment for signs of external degradation (for example, corrosion), deformation, and process leakage. The inspection also examines the equipment support, grounding, ladders, platforms, and other associated pieces of hardware;

- In-service inspection – An inspection of the equipment while in operation that uses non-destructive methods to monitor damage mechanisms associated with the equipment's service. The non-destructive methods are selected specifically for the potential damage mechanism and take into consideration limitations of the method. Also known as an on-line inspection; and

- Routine inspection – An inspection that typically consists of brief checks on equipment condition at a basic level. These checks can provide value because they can detect unusual conditions or incipient damage, can be performed on a regular basis, and at a high frequency in comparison to more detailed inspections. They are particularly useful for equipment in remote locations where damage could otherwise go undetected for some time.

At a minimum, the inspection of equipment shall include an external visual inspection. This can often be supplemented by an internal inspection if a degradation mechanism affecting the inner surface has been identified or is suspected.

An inspection may be made up of a combination of inspection strategies supplemented with routine inspections. Typically, the preferred inspection method is NDE. However, in some cases integrity assessment may be based on destructive examination of samples removed from the equipment. For instrumentation and electrical equipment, an inspection method may include functional testing.

Specific types of inspection methods are described in Section 14.

7.2 Strategies for determining testing or inspection interval

There are a number of approaches to determining the interval between inspections or testing. One option is to use a prescriptive approach. This is based on information that may be provided by the equipment manufacturer, technical literature, regulation, and industry or company experience.

Another option is to carry out a risk-based inspection (RBI), which is a recognised formal method of identifying appropriate inspection techniques, where these should be applied, and how often for a piece of equipment. The term RBI is often used to refer to the formal process whereby a group of individuals with a detailed knowledge of the item of equipment being considered reviews the process and design of the equipment, assesses the likely modes of failure, and agrees how these can be mitigated by routine inspection. The final outcome is a directed inspection plan. In a RBI, the review of the design of the equipment and processes involved leads to the identification of the hazards of failure and lists a number of possible failure mechanisms. These are then used to assess the risk associated with the failures and ways that these can be mitigated. If these mitigation measures include the examination of the equipment, then an inspection plan is drawn up to define that inspection. A RBI may justify inspection methods that are more effective, less invasive, and safer to implement than more conventional basic internal inspections. For more information on RBI, see API 580, *Risk Based Inspection* [10].

A third option is to calculate the next inspection interval as a proportion of remaining life, based on measured or predicted degradation rates. This is considered an evidence-based approach. This approach requires a safety factor to be applied to account for uncertainty in the rate of degradation. The concept of half remaining life is commonly used. Examples of an evidence-based approach are in Section 6 of EEMUA 159, *Above Ground Flat Bottomed Storage Tanks: A Guide to inspection maintenance and repair* and API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair and Alteration* [11, 12].

Predicted degradation rates are usually the most accurate when based on historical evidence from the equipment and process in question. However, where this is not available, evidence from similar situations or degradation rates taken from published guidance may be used. The reliability of predictions should always be considered when basing assumptions upon them, and attempts should be made to build up historical evidence and increase the reliability over time.

8 Inspection

It is often impractical to carry out the inspection if the equipment is not prepared correctly. Therefore, it is important that the formal inspection plan clearly defines all the steps that need to be taken to prepare the equipment.

Safety aspects of preparing for and carrying out an inspection such as confined space, work permit, energy isolation are outside the scope of this publication. However, these aspects shall be considered as a part of a formal inspection plan.

8.1 Individuals involved

It is important that during an inspection the inspector knows what to look for. Although some modes of deterioration may have been identified prior to the inspection, the inspector should always be prepared for other types of damage.

Periodic inspection involves a number of parties, each having an important role in the success of the integrity assessment. They include:

- Operations management of the equipment including the planning department as well as production, maintenance, and procurement staff;
- Notified body / competent authority / accredited organisation – for example, employees of operations management or third-party organisations;

- NDE contractors employed to carry out supplementary activities in support of the periodic inspection; and

- Contractors employed to prepare the plant for inspection – for example, scaffolding, insulation, or refractory contractors, tank or vessel cleaners etc.

All of those identified previously need to establish and maintain effective methods of communication in order to carry out a suitable inspection plan.

8.2 Inspections during plant shutdowns

Within the process industries, it is common for plants to be periodically shutdown for overhaul and maintenance, making large numbers of equipment available for inspection at the same time. This can introduce its own issues to the inspection process. For the effective planning of a shutdown, it is important that sufficient time is allocated for inspection of the plant. This should include allowance for:

- Plant preparation including scaffolding, removal of insulation, depressurising, purging, cleaning, isolation from all sources of energy and chemicals, and necessary arrangements for confined space entry;

- Initial overview inspection – allowing time to carry out a plant walk around to establish general condition or identify any obvious defects / deterioration;

- Detailed inspection in accordance with any existing formal inspection plan. This should include any supplementary NDE activities; and

- Whenever possible, time to respond to potential repairs that could be required as a result of the inspection. Those involved in the shutdown should be able to respond to the demands placed upon them by the requirement for inspection, including time pressures placed upon them to get the plant back into operation.

Any variations from the inspection plan should be fully justified and not affect the safety of the plant. The justification needs to be based on continued plant safety and not operational demands. This requires the independence of decision making. Justifications should be fully documented.

8.3 Management of findings during inspection

It is important that any discrepancies and deviation from the inspection plan are effectively communicated to the appropriate decision makers including:

- Inability to complete an inspection due to time or access restrictions – the inspector needs to clearly identify what affect this could have on establishing the suitability of plant for continued service;

- Defects / deterioration that could require remedial work within a specified time or require changes to future inspection plan; and

- Defects / deterioration found that require immediate rectification. It is important that this is communicated so that the appropriate remedial action is taken.

9 Post assessment

All inspection and testing findings shall be assessed. Individuals conducting the assessment should have the necessary competencies to carry out this review / assessment.

The assessment is to provide for a final adjudication of the inspection and test findings and to ensure that a final, formal documented statement is made on the suitability of the equipment to return to service or not.

9.1 Assessment of deterioration

As part of the assessment, any deterioration identified during inspections and tests shall be reviewed. This can be within previously defined limits (for example, corrosion allowance) and be considered acceptable to allow continued use. In other cases, further work is required. This process is often referred to as a fitness for service assessment or engineering criticality assessment and is a re-evaluation of the integrity for continued service.

Fitness for service assessment can cover a wide range of activity from a screening engineering assessment to detailed design review and possibly finite element analysis. For assessment of deterioration, rates of deterioration should be determined to confirm that the equipment can remain safe to operate until the next inspection and the remaining life of the equipment.

9.2 Changes to subsequent inspections

As with any other working document, the formal inspection plan should be reviewed to ensure that it is still relevant and fulfils its prime purpose of defining the inspection required.

A suitable opportunity for this review is immediately after a scheduled inspection when the formal inspection plan was used, especially for the first time in a number of years. Reviewing the formal inspection plan at this time allows the inspector who has just completed the inspection to make comments and to take account of the experience. In particular, care needs to be taken to ensure that any deterioration noted has been as a result of one of the modes of deterioration already included in the inspection plan. If this defect is as a result of an unexpected damage mechanism, then it needs to be added to the inspection plan along with the inspection necessary to look for it.

Deterioration identified during inspections should be incorporated into the inspection plan to advise where future inspections and tests need to be concentrated. In addition, where other equipment is in service in a similar duty then consideration needs to be given to the updating or amending of the plan for that equipment to reflect the deterioration identified elsewhere.

Where no deterioration is noted, this should be incorporated into the plan.

9.3 Assessment record

The documented assessment record should include:

- Inspection reports;
- Clear and unambiguous statement(s) as to the equipment’s ongoing fitness for service;
- Record(s) of deterioration;
- Prediction that current deterioration can remain within acceptable limits by the next inspection;
- Dates for future inspections to be carried out. This is typically a calendar date but may also include additional parameters such as running hours, operational cycles, changes in process;
- Limitations to the equipment’s use;
- Statement that the formal inspection plan continues to remain suitable or details of any necessary changes required to the plan; and
- Details of required repairs when the equipment is not considered suitable for further service.

9.4 Repair, rerate, or retire

Usually a repair is the preferred route to return the plant to the original duty. Repairs need thorough specification and planning to ensure that the original duty can be maintained. On completion of repairs, further inspection may be required to verify that the repair is satisfactory.

When repairs are necessary for the continued use of equipment, these should be carried out to recognised standards and plans to complete the repairs. The quality of repair parts and maintenance materials should be ensured. As a minimum, the following documentation shall be kept:

- Specification of and approval for the repair;
- MOC records; and
- Quality assurance requirements.

The information relating to the repair should be included and / or referenced within the final, documented review/assessment and the repairs confirmed to be satisfactory.

Repairs are not always possible or cost effective and an alternative is to rerate the plant and continue to use it for a less arduous application (for example, at a less demanding pressure or temperature).

When a repair or rerating is not possible, retirement/decommissioning and replacement of the equipment may be the only option.

Any repair, rerate, or replacement shall be covered by a MOC process. See EIGA Doc 51, *Management of Change* [9].

9.5 Incomplete or postponement of inspections

Situations can arise when it is not possible to complete a formal inspection on equipment at the scheduled time. However, the inspection should not be just allowed to become overdue or remain incomplete. A formal process to postpone the inspection due date or complete the inspection should be undertaken.

Equipment should be subject to a process, including competent assessment and approval, to provide justification and independent oversight of the proposed postponement or incompletion.

10 Inspection, testing, and preventive maintenance reporting

Equipment integrity inspections are inspections whose intent is to prevent loss of containment that can result in unacceptable safety or environmental risk. Following any equipment integrity inspection, testing, and preventative maintenance (ITPM) task, it is imperative the results of the task are well documented and the operations management of the plant/equipment has systems and processes in place to manage the ITPM task report documentation. It is the responsibility of the competent person to generate the ITPM inspection results in a formalised report and send to the integrity management team (or individuals identified by the team). It is highly recommended for the person performing the ITPM task to review the past maintenance strategies and performance of the plant/equipment. This review can include known damage mechanisms, reliability and failure history, past ITPM tasks conducted, corrosion readings at circuit condition monitoring locations (CMLs), any past fitness for service assessments, past inspection methodologies, and required acceptance criteria. Any trending anomalies observed from the plant/equipment review should be referenced in the ITPM report.

The purpose of the ITPM inspection report is to clearly record the inspection, stating what task was performed as well as to provide the results of the overall integrity of the plant/equipment. The report should meet any special requirements predetermined in the inspection plan and should be timely and accurate. The inspection results should be documented every time an ITPM task is performed for the equipment and/or its ancillaries, regardless of who conducts the task.

The results of an ITPM inspection report may differ slightly based on the type of ITPM task being conducted but, at a minimum, the inspection report should contain the following information:

- name and address of the site;
- identification of the plant or equipment;
- inspection plan;
- name and company of the inspector(s);
- date;
- inspection types;
- equipment that was examined/not examined;
- results of NDE reports;
- overall condition assessment of the plant/equipment; and
- results including any plant or equipment anomalies.

Additional suggested information to be included in the ITPM inspection report includes:

- qualification records of the personnel;
- spare parts or other materials used or replaced;
- quality assurance (QA) and/or MOC records;
- condition of the equipment;
- any abnormal operating conditions since last inspections;
- remaining life calculations; and
- recommended corrective actions.

11 Record keeping

As part of a plant integrity management system, it is necessary for operations management to keep accurate, up to date records. This ensures that decisions about the specific integrity of an individual piece of equipment can be easily traced and justified. These records should include:

- documentation confirming the safe operating limit of the equipment;
- manufacturing information such as material information, welding information, testing information, etc.;
- planned and reactive maintenance;
- reports of inspection / testing;
- information on any repairs / modifications;
- formal inspection plans including records of amendments;

- information relating to incomplete inspections or postponements;
- operating conditions and the operating history of the plant / equipment;
- associated risk assessments, periodic reviews, ageing plant reviews; and
- other reports that contain information relevant to the assessment of safety.

While the previous list is not completely exhaustive, it is a good guide as to the type of information that is necessary. See Section 5.

These records should be accessible by the relevant personnel involved in integrity management.

12 Integrity management of electrical, control, and instrumentation and safety systems

This section is intended to provide guidance regarding technical and managerial issues surrounding ageing of electrical, control, and instrumentation (EC&I) and safety systems.

Any EC&I system is potentially within scope if its failure can cause an unacceptable event / energy release / leaks.

Examples of components and equipment with the possibility to lead to dangerous events / energy release / leaks:

- contactors/breakers (high voltage: possibility of arc flash);
- transformers (in dry transformers: arc due to loss of phase insulation; high voltage oil-filled transformers: porcelain ejection and possible fire due to bushings' loss of insulation);
- connection box for the power cables (rainwater ingress); and
- impulse tubing of transmitters (rupture of tubing, coupling coming loose).

Examples of components ensuring that the plant or equipment stays within safe operating limits:

- safety instrumented system (SIS) components:
    - sensors (pressure, level, temperature)
    - logic solver
    - control elements (generally valves, sometimes motors);
- pressure relief devices and shutoff valves; and
- electric motors (for example, as part of backup systems for permanent cooling).

Safety systems are designed to isolate, contain, or release energy in controlled manner through shutdown systems, trips, alarms, etc. (for example, overfill protection systems for bulk storage tanks).

For managing major hazards, it shall be clear which of these EC&I systems are safety critical. This may be established through a variety of techniques including safety integrity level (SIL) assessment, layer of protection analysis (LOPA), hazard identification (HAZID), and hazard and operability (HAZOP) studies.

12.1 Degradation mechanism of electrical, control, and instrumentation systems and equipment

EC&I systems and equipment can be affected by the same degradation mechanisms as mechanical equipment such as corrosion, erosion, fatigue, etc. However, they can also be subject to more EC&I specific degradation mechanisms. These include physical mechanisms such as:

- impact damage or surface abrasion;
- overheating / burn damage;
- blockage;
- instrumentation aspects such as instrument drift;
- exposure to environmental conditions; and
- water ingress.

As with mechanical plant activities, quality control of plant painting activities can affect EC&I systems (for example, the painting of flameproof glands or painting over instruments).

EC&I systems typically have a shorter working life compared to some mechanical systems due to the software that is used, which can become obsolete or difficult to support.

On the other hand, software-based EC&I systems can provide significant advantages to safety in terms of improved control and diagnostic information as well as providing economic advantages compared to older style analogue systems.

12.2 Integrity management

The subject of ageing of EC&I systems and equipment differs from mechanical parts:

- Many of the components of EC&I systems can be tested at reasonable impact (during a regular maintenance stop) and can be changed out at relative low cost;
- EC&I components are subject to both infant mortality and aging effects. A maintenance programme should include tasks to address validation of the initial installation and ongoing service of the EC&I component. For components being part of a safety instrumented loop, databases with failure rates are typically used to determine a proper test frequency; and
- Generally, components of EC&I systems that are part of a protection loop are fail safe. Defects usually lead to a plant reliability issue (shutdown of the unit) rather than an integrity issue.

Integrity shall be ensured for the instrumentation field equipment such as tubing that can lead to an unacceptable safety or environmental risk in case of failure.

Since the 1990s, international standards such as IEC 61508-5, *Functional Safety Of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 5: Examples Of Methods For The Determination Of Safety Integrity Levels* and IEC 61511, *Functional safety-Safety instrumented systems for the process industry sector-Part 1: Framework, definitions, system, hardware and application programming requirements* have provided a lifecycle-based framework for successfully deploying such systems [13, 14]. Also, a number of guidance documents have been produced (for example, EEMUA 222, *Guide to the application of IEC 61511 to safety instrumented systems in the UK process industries)* [15].

With care, even sophisticated EC&I equipment can be kept working to a remarkable age. Other equipment may need replacing after short timescales. Digital (or software–based) equipment shows a tendency to have significantly shorter lifecycles.

For more information, see HSE RR823 and its accompanying Summary Report [3, 4].

13 Degradation mechanism

This section provides a brief, but not exhaustive, introduction to the more common mechanisms that lead to age related deterioration of process equipment. The mechanisms discussed include corrosion, cracking, and material deformation, which are caused by process and environmental conditions.

It is intended to provide concise and focused information for non-specialists (for example, those involved in management of ageing plants) to help them understand the key issues affecting mechanical integrity of process equipment.

Comprehensive listing and information on damage mechanisms in process plants for equipment engineers, specialists, and inspectors can be obtained from documents such as API 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry* [16].

13.1 General or local corrosion

Corrosion is a chemical reaction between the materials of the pressure system and the process fluid or the external environment.

- Wet aqueous corrosion is the most commonly encountered form of corrosion, which takes place when moisture is present at less than its dew point;

- Dry hot corrosion can take place at temperatures greater than 400 °C (752 °F);

- General corrosion (a uniform loss of wall thickness) of pressure systems can be hazardous and result in potential catastrophic failure; and

- Localised corrosion, pitting, or crevice corrosion can be damaging to equipment and be difficult to detect due to its localised nature and speed of development; however, it is more likely to lead to a leak before failure.

The presence of corrosion does not indicate that the equipment is not fit for service, just that the equipment is ageing. In cases of metal loss less than the specified allowance, an assessment or a fitness for service review should be completed to determine suitability for continued service.

The impact of corrosion can be eliminated or reduced at the equipment design stage by considering factors such as material selection, protective coatings, cathodic protection, and water treatments. At the design stage, a corrosion allowance is also normally included for ferrous equipment intended to operate in a corrosive environment.

13.2 Atmospheric corrosion

Corrosion due to the effects of moisture and oxygen combined with contaminants such as sulphates, nitrates, chlorides on exposed structures.

Atmospheric corrosion is similar to wet corrosion but generally occurs at a lower rate unless pollutant levels are high, for example, in marine or industrial (sulphate or nitrate) environments.

Corrosion under insulation (CUI) is the external corrosion of steel equipment and structures that occurs underneath jacketed thermal or acoustic insulation. CUI can occur when moisture and pollutants (for example, chlorides) get under insulation and create aggressive localised damage. When undetected, CUI can lead to the shutdown of a process unit or an entire facility, and in rare cases it can lead to a process safety incident. CUI depends on many parameters such as metal temperature, insulation material and design, equipment material, and external environment. For more information on CUI, see API RP 583, *Corrosion Under Insulation and Fireproofing* [17].

13.3 Galvanic corrosion

Corrosion due to electrochemical action between two metals with different electrode potentials. For example, if a cell is allowed to form with an electrolyte linking steel and aluminium, the aluminium becomes the anode and corrodes. If the surface area of the steel is much larger than that of the aluminium, the rate of loss of aluminium is proportionately greater.

13.4 Erosion corrosion

Erosion corrosion is caused by high flow or abrasive process conditions stripping the metal surface. This mechanism is more commonly known as flow accelerated corrosion. Erosion corrosion is a combined effect where the corrosion product layers is stripped away by the erosion mechanism.

13.5 Stress corrosion cracking

Stress corrosion cracking (SCC) is a form of corrosion where a corrosive element such as chlorides or caustics penetrates a stressed material forming corrosion between material grain boundaries.

SCC is a condition that requires the simultaneous presence of a susceptible material, a tensile stress, and a susceptible environment. Stainless steels (with chlorides) and brasses (with ammonia) are particularly vulnerable to SCC. Carbon steels can be affected (ammonia or nitrates). The rate of corrosion increases with temperature until moisture is no longer present.

SCC can occur under insulation or in confined spaces where pollutants can concentrate.

13.6 Pitting (crevice) corrosion

A form of galvanic corrosion where an electrolytic cell is established in the same material, usually under debris deposits. Corrosion is in localised areas and can rapidly advance through otherwise sound material. This form of attack is one of the main forms of corrosion observed in corrosion-resistant steels.

Crevice corrosion is a similar mechanism to pitting corrosion. Attack typically forms around and under items such as washers and bolts.

13.7 Fatigue cracking

Fatigue cracking is the formation of cracks due to cyclic mechanical or thermal loading over time.

Cracks are most likely to form at high stress concentrations or notch areas such as weld seams and nozzle welds. The cracks propagate through the material thickness due to repeated loading until failure.

Fatigue can be reduced at the design stage by lowering material stress and stress ranges, lowering stress concentrations, and using lower strength materials with high fracture toughness.

Bolts in systems under cyclical stress shall be designed and installed with sufficient prestressing so that the bolts are not subject to cyclical stress.

13.8 Corrosion fatigue

Corrosion fatigue is a damage mechanism from the effect of both corrosion and fatigue. Specific corrosion creates areas of stress concentration that become crack initiation sites for fatigue cracking.

13.9 Erosion

Erosion is where material is removed by the scouring action of a fluid or particles contained within the fluid. Examples include:

- flow impingement points for fluids containing rust particles;

- pressure system leaks within perlite insulation where the abrasive perlite erodes the metal and increases the leak rate; and
- steam leaks where the steam condition change erodes joint faces.

13.10 Cavitation corrosion

A form of mechanical damage to metal surfaces caused by the implosion of cavitation bubbles. The energy directed into the material when the bubbles implode can cause significant metallurgical damage and material loss. Examples are at the pump inlet, at the discharge of a valve or regulator in two-phase flow.

13.11 Carbon dioxide (sweet) corrosion

Carbon dioxide (sweet) corrosion is corrosion as a result of dissolved carbon dioxide forming an acidic (sweet) solution, which results in metal wall thinning and shallow pitting. Under high flow conditions, deep elongated pits are sometimes observed. Low alloy steels are more susceptible to this form of corrosion. Typically at temperatures greater than 80 °C (176 °F), an iron carbonate film can result in lower than expected corrosion rates.

13.12 Hydrogen sulphide (sour) corrosion

Hydrogen sulphide (sour) corrosion is corrosion as a result of dissolved hydrogen sulphide forming an acidic (sour) solution. The low solubility of the resulting iron sulphide results in the formation of a dark black film that protects the steel from aggressive corrosion; however, any break in the iron sulphide layer can result in very severe pitting.

13.13 Microbiological corrosion

Microbiological corrosion is caused by the contamination and growth of micro-organisms such as bacteria and algae. The micro-organisms attach to metal surface causing pits and cavities. This form of corrosion is typically found in stagnant water, dead legs, and bottom of tanks.

Conditions required for microbiological corrosion include bacterial life, sulphide, carbon, water, close to neutral pH, and temperature suitable for bacterial life.

13.14 Metal dusting

Metal dusting is a type of high temperature corrosion that occurs in the temperature range of 400 °C to 800 °C (752 °F to 1472 °F) and in a carbon monoxide-hydrocarbon atmosphere with high carbon activity. Metal dusting is characterised by pitting and soot on the surface. This degradation mechanism includes the deposit of carbon on the surface of the metal, diffusion into its structure, and growth of graphite grains that eventually leads to destruction of the material.

13.15 Creep

Creep is a time dependent deterioration at elevated temperatures in constant stress conditions resulting in deformation of the metal, wall thickness reduction, and potential stress rupture. At the design stage, consideration should be given to the material creep threshold and range in relation to its required operating conditions.

13.16 Concrete degradation

Process equipment are typically supported by concrete structures that are also subject to deterioration over time. The principal causes of concrete deterioration are settlement, erosion, cracking, and deterioration of concrete initiated by carbonation, attack by underground water, frost, cryogenic liquid, chlorides, alkalis, and acids.

Some mechanisms of concrete deterioration are:

- Carbonation, which is a slow and continuous process that occurs when concrete reacts with carbon dioxide from the air. It results in the formation of calcium carbonate and water;

- Deterioration of concrete exposed to underground water that can be caused by chemical attack, by cyclic changes in temperature, and by freezing moisture;

- Expansion of freezing moisture in porous concrete, or in concrete with minor settlement cracks or temperature cracks can result in deterioration and / or the development of serious structural cracks; and

- Lubrication oil leak of a machine onto the concrete foundation can lead to concrete deterioration.

Monitoring and assessment are covered by EN 1504-9, *Products and Systems for the Protection and Repair of Concrete Structures. Definitions, Requirements, Quality Control and Evaluation of Conformity. General Principles for Use of Products and Systems* [18].

13.17 High temperature hydrogen attack

High temperature hydrogen attack (HTHA) is a degradation mechanism occurring in dry hydrogen atmospheres at elevated temperatures (typically greater than 400 °C [752 °F] for chromium molybdenum steels and 210 °C [410 °F] for carbon steels) and with sufficient hydrogen partial pressure. The hydrogen molecule dissociates into atomic hydrogen and then either decarburises the surface or diffuses into the steel where it reacts with certain metal carbides to form methane gas. This gas accumulates in the grain boundaries and precipitate interfaces, slowly increasing in pressure and volume thus leading to cracking. For more information on HTHA, see API 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants* [19].

13.18 Aluminium sensitisation

Under thermal conditions, aluminium alloys from the 5000 family (magnesium-containing aluminium alloys) can suffer precipitations at grain boundaries of intermetallic compounds (Mg_2Al_3 and Mg_5Al_8). This sensitisation impairs the corrosion resistance towards intergranular corrosion and SCC as well as the mechanical properties due to the variation in the microstructure (for example, the precipitation of β-phase and / or decrease in solute magnesium concentration in the matrix). Sensitisation is increased by the magnesium content of the alloy, the service temperature, and holding time.

14 Detection and sizing of defects and damages

14.1 Inspection procedures

An inspection is most effective if the potential damage mechanisms and locations where that damage is most likely to occur have been identified, and methods to detect any significant defect are considered in advance of any inspection. Inspection methods can be a combination of either destructive testing or NDE.

For each inspection, a procedure should be written and validated by a competent person. The goal of the inspection, precautions, and the type of defect and characterisation requirements should be described.

14.2 Inspection methods

The following section gives a summary of inspection methods suitable for the detection, sizing, and assessment of different types of damage. This summary is not meant to be exhaustive. For further information, see HSE RR509 [6].

NDE can be used to effectively monitor corrosion rates, crack propagation, and other damage mechanisms; however, it is important to understand the reliability, capability, and limitations of any NDE technique used. Selecting the appropriate NDE method for the potential damage mechanism is critical to developing a successful inspection plan. These techniques require a competent person to correctly interpret the results and avoid possible false indications.

For example, NDE can be required to measure the remaining wall thickness where corrosion or erosion could have removed some of the original material or examine for other signs of damage. In most cases, the type of NDE should be specified in the formal inspection plan. However, it is important not to make the formal inspection plan so specific that it reduces the freedom of the inspector to use a different technique if considered relevant.

Depending on the NDE method applied, additional specific procedures may be necessary before putting the equipment back in operation (for example, cleaning for oxygen service, degaussing after magnetic particle inspection.

14.2.1 Visual inspection

Visual inspection is one of the most effective inspection techniques, which offers a large amount of information in a short time and allows other methods to be applied where appropriate.

A visual inspection can only be effective with adequate access, surface preparation (if necessary), lighting, competence, and physical ability (eyesight) of the person conducting the inspection.

Remote forms of inspection including the use of binoculars, digital cameras, drones, endoscopes, and borescopes can be used to enhance visual inspection.

14.2.2 Wall thickness measurement

The wall thickness of a pressure system is often measured using ultrasonic equipment. This can determine material loss due to damage mechanisms such as corrosion, erosion, metal dusting, etc. The equipment requires calibration, interpretation, and often internal or external surface preparation. Basic digital thickness meters may not be sufficient for some inspections. Damage in the form of pitting may require the use of additional techniques such as pit depth gauges or other forms of inspection.

Any method used shall take account of paint thickness.

14.2.3 Dye penetrant examination

Dye penetrant examination is regularly used to detect cracking or other defects such as weld porosity on bare metal surfaces.

This method is simple but can give false positives and requires a competent person for correct interpretation. It may not identify significant cracks that are in compression.

This method is a quick and flexible method for detecting surface breaking cracks and is commonly used to support examinations that are looking for defects that have developed in service. This may not be effective on surfaces that have been painted if the paint has not been adequately removed.

14.2.4 Magnetic particle inspection

Magnetic particle inspection is regularly used to detect cracking on magnetic pressure equipment.

This method is widely used for carbon steel material. However, it is ineffective on austenitic stainless steel, aluminium, and copper-based materials.

14.2.5 Ultrasonic testing

A variety of ultrasonic test methods are available and commonly used for identifying crack-like indications in pressure systems. Each method has its advantages and limitations.

Both surface and sub-surface indications can be identified. With appropriate calibrated equipment, complex joints such as nozzle welds can be effectively examined and internal surface defects identified from the outside.

This method is commonly used to support examinations that are looking for defects that have developed in service.

14.2.6 Eddy current examination

Eddy current examination methods are available and commonly used for identifying a variety of different defects. Each method has its advantages and limitations. The selection of the specific technique is determined by materials of construction and the purpose of the inspection.

14.2.7 Radiographic examination

Radiographic examination (X-ray or Gamma ray) is a common method for examining, approving, and recording new construction welds. Radiography is particularly good at identifying voids, inclusions, lack of fusion, poor weld profiles etc. Radiography can be used for in-service damage such as determining wall loss on small bore piping or crack detection on welds but has limitations on its detection limits that shall be considered when developing an inspection plan.

14.2.8 Thermography

Thermography is a method of viewing the temperature profile of pressure systems and equipment. It can be used to check for cryogenic leakage, insulation degradation, electrical hot spots, etc.

15 References

Unless otherwise specified, the latest edition shall apply.

[1] Directive 2012/18/EU *on the control of major-accident hazards involving dangerous substances* (Seveso III Directive), www.europa.eu.

[2] *Code of Federal Regulations*, Title 29 (Labor), www.gpo.gov.

[3] HSE RR823, *Plant Ageing Study – Phase 1 Report*, www.hse.gov.uk.

[4] HSE RR823, *Summary Report, Managing Ageing Plant—A Summary Guide*, www.hse.gov.uk.

[5] EEMUA 231, *The mechanical integrity of plant containing hazardous substances—A guide to periodic examination and testing*, www.eemua.org.

[6] HSE RR509, *Plant Ageing: Management of Equipment Containing Hazardous Fluids or Pressure*, www.hse.gov.uk.

[7] *Dealing with Aging Process Facilities and Infrastructure*, Center for Chemical Process Safety (CCPS). www.aiche.org.

[8] ISO 31000, *Risk management—Guidelines*. www.iso.org.

[9] EIGA Doc 51, *Management of Change*, www.eiga.eu.

[10] API 580, *Risk Based Inspection*, www.api.org.

[11] EEMUA 159, *Above ground flat bottomed storage tanks: A guide to inspection maintenance and repair*, www.eemua.org.

[12] API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair and Alteration*, www.api.org.

[13] IEC 61508-5, *Functional Safety Of Electrical/Electronic/Programmable Electronic Safety-Related Systems- Part 5: Examples Of Methods For The Determination Of Safety Integrity Levels*, www.cen.eu.

[14] IEC/EN 61511, *Functional Safety-Safety Instrumented Systems for the Process Industry Sector*, www.cen.eu.

[15] EEMUA 222, *Guide to the application of IEC 61511 to safety instrumented systems in the UK process industries*, www.eemua.org.

[16] API 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*, www.api.org.

[17] API 583, *Corrosion Under Insulation and Fireproofing*, www.api.org.

[18] EN 1504-9, *Products and Systems for the Protection and Repair of Concrete Structures. Definitions, Requirements, Quality Control and Evaluation of Conformity. General Principles for Use of Products and Systems,* www.cen.eu.

[19] API 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*, www.api.org.

[20] EIGA Doc 170, *Safe Design and Operation of Cryogenic Enclosures*, www.eiga.eu.

NOTE This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

[21] EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites*, www.eiga.eu.

NOTE This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

16 Additional references

EIGA Doc 40, *Work Permit Systems*, www.eiga.eu.

EIGA Safety Info HF-01, *Human Factors – An Overview*, www.eiga.eu.

EIGA Safety Info HF-02, *Individual “Training and Competence*”, www.eiga.eu.

EIGA Safety Info HF-05, *Task Maintenance Error*, www.eiga.eu.

Appendix A – Cryogenic coldbox located pressure equipment (Informative)

A coldbox is the cylindrical or rectangular enclosure, typically metal, surrounding the cryogenic pressure equipment (distillation columns, exchangers, separators, vessels, associated piping, instrumentation).

The industrial gases industry generally does not carry out periodic inspection of cryogenic equipment within a coldbox.

Periodic inspections of cryogenic equipment are not carried out for the following reasons:

- Industry operating experience;
- Cryogenic plants are constructed from materials that have low corrosion potential. These materials retain their corrosion resistance at temperatures less than ambient and experience shows that corrosion at cryogenic temperatures is negligible;
- Process fluids are dry, clean, and non-corrosive;
- Limited impact of the traditional failure mechanisms for such equipment: namely erosion and fatigue due to the external cryogenic coldbox structure;
- Design and construction are carried out to well established and internationally recognised codes and standards. Design takes into account pressures, loadings, temperature changes, and movements expected during normal running and during start up and shutdown;
- Operating mode of a cryogenic air separation plant is generally steady state with few pressure and temperature variations;
- Materials used in the construction have high fracture toughness characteristics. The critical defect size for the initiation of an unstable fracture can allow a defect to be detected from an increase in coldbox pressure or from the presence of cold patches well before the critical defect size is reached; and
- Materials used in the construction have significantly enhanced yield and ultimate tensile strengths at their working temperature. For example, at cryogenic temperature the ultimate tensile strength of austenitic stainless steel is approximately twice that at ambient temperature.

In the industrial gases industry, there have been incidents where failure of the enclosure has been reported. A periodic inspection and maintenance plan shall be set up to ensure integrity of the enclosure (for example, tightness, embrittlement of the carbon steel structure, purge gas, icing, perlite level, vacuum). Inspections should confirm that the environment within the coldbox is dry, inert, and that there are no indications of cryogenic and/or pressure leaks.

The inspection includes actions to manage the risk of pressure release and loss of cryogenic inventory from coldbox located pressure equipment. Guidance on coldbox design is given in EIGA Doc 170, *Safe Design and Operation of Cryogenic Enclosures* [20].

Appendix B – Cryogenic bulk storage tanks at production sites
(Informative)

The industrial gases industry generally does not carry out periodic internal inspection of cryogenic bulk storage tanks at production sites.

Periodic internal inspections of cryogenic storage tanks at production sites are not carried out for the following reasons:

- Industry operating experience;
- Inherently stable and benign conditions within an operating cryogenic storage tank and an absence of the traditional failure mechanisms for such equipment namely corrosion, erosion, and fatigue;
- Cryogenic storage tank inner vessels are constructed from materials that are corrosion resistant. These materials retain their corrosion resistance at temperatures less than ambient and experience shows that corrosion at cryogenic temperatures is negligible;
- Process fluids are dry, clean, and non-corrosive;
- Design and construction are carried out to well established and internationally recognised codes and standards. Design takes into account pressures, loadings, temperature changes, and movements expected during normal running and during start up and shutdown. The design also takes into account that inner tank and associated piping are largely inaccessible within an outer jacket;
- Operating mode of cryogenic storage tanks is generally steady state with few pressure and temperature variations;
- Materials used in the construction have high fracture toughness characteristics. The critical defect size for the initiation of an unstable fracture can allow a defect to be detected from an increase in interspace pressure or from the presence of cold patches well before the critical defect size is reached; and
- Materials used in the construction have significantly enhanced yield and ultimate tensile strengths at the working temperature. For example, at cryogenic temperature the ultimate tensile strength of austenitic stainless steel is approximately twice that at ambient temperature.

An annual inspection should be carried out to guard against any degradation mechanisms developing and to confirm that the environment within the tank outer jacket is dry and inert and that there are no obvious indications of cryogenic and/or pressure leaks. Additional periodic assessments may be considered. Aspects of these assessment may include:

- service history review; and
- external inspection review including previous reports, relief valve inspections, etc.

The annual inspection includes actions to manage the risks from overpressure and overfilling that may result in loss of containment. Guidance on the design of bulk cryogenic tanks is given in EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites* [21].