PLANT INTEGRITY MANAGEMENT

IGC Doc 190/14

EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL

AVENUE DES ARTS 3-5 • B – 1210 BRUSSELS
Tel: +32 2 217 70 98 • Fax: +32 2 219 85 14
E-mail: info@eiga.eu • Internet: www.eiga.eu

PLANT INTEGRITY MANAGEMENT

EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL
Avenue des Arts 3-5 B 1210 Brussels Tel +32 2 217 70 98 Fax +32 2 219 85 14
E-mail: info@eiga.eu Internet: www.eiga.eu

Table of Contents

1 Introduction

This document has been prepared by member companies of EIGA to establish a common position and give guidance on Plant Integrity Management (PIM); this topic is also referred to as Plant Ageing and it is increasingly included in authority inspections of plants subject to the Seveso II Directive 2003/105/EC [1]. [1, 2]

Ageing is not about how old is equipment; it is about its condition and how that is changing over time. Ageing is the effect whereby a component 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. Ageing equipment is equipment for which there is evidence or likelihood of significant deterioration and damage taking place since new. See HSE RR823 *Plant Ageing Study – Phase 1 Report* [2].

The integrity of process plant can be ensured by a documented programme of procedures, training, inspections, and tests and through preventive/predictive maintenance based upon good engineering practice, applicable codes, standards, specifications and manufacturers' recommendations.

It is important to recognise that many systems and features that can be subject to ageing, can contribute to the health, safety and environmental performance of a plant or could compromise the performance were they to fail or collapse. A broad view is therefore required when assessing the potential impact of ageing at a given installation.

This document may be used as part of demonstrating compliance to the Seveso Directive [1]. Within the Seveso directive, the term “establishment” is defined as being “the whole location under the control of an operator”, whereas in this document “site” has been used. The two terms are considered interchangeable for the purpose of this document.

2 Scope and purpose

2.1 Scope

This document gives generic guidance on the integrity management of process plant containing hazardous substances.

Process plant includes process equipment, piping and their primary protection devices, electrical and instrumentation systems, structures and foundations where a failure could lead to a loss of containment.

2.2 Purpose

The purpose of this document is to give guidance on plant integrity management to designers, manufacturers and operators within the industrial gases industry to ensure the safety of equipment containing hazardous fluids. Much of the guidance is similar to that in the general process industry. However, recommended inspection procedures for equipment specific to the industrial gases industry, where the lack of potential deterioration mechanisms makes traditional internal periodic inspections inappropriate, are included as appendices.

---

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

[2] A review of the Seveso II Directive 96/82/EC has been concluded. As a result of the review process the European Commission adopted a proposal for a new Directive that would repeal and replace the current Directive by 1st of June 2015.

3 Terminology and Definitions

For the purpose of this document, the following terminology and 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 and need not

Indicates that the procedure is optional.

3.1.4 Will

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

3.1.5 Can

Indicates a possibility or ability.

3.2 Definitions

3.2.1 Ageing

The effect whereby a component 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 the lifetime.

3.2.2 Competent person

An individual or a body corporate of several people who have the theoretical knowledge, practical experience and training to identify design defects, to detect mechanical defects, to assess their importance and to ultimately endorse or otherwise an equipment as fit for continued service.

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

3.2.3 Formal periodic inspection scheme

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

3.2.4 Hazardous substances

Is a substance with a potential for creating damage to human health and or to the environment.

4 Plant integrity management system

4.1 General

The following guidance is based on recommendations included in EEMUA Publication 231 – SAFed Publication IMG 1: *The mechanical integrity of plants containing hazardous substances* [3]; HSE RR509 *Plant Ageing – Management of equipment containing hazardous fluids or pressure* [4].

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

Whilst this guidance is focussed towards inspection, it is very useful to put this into context, as this is only one element of an integrity management strategy. If the plant was not specified, designed or constructed correctly, on-going integrity management can require a unique approach and be problematic. Also key to maintaining integrity is the assessment of the results of inspections, especially where 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 remanent 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 scheme reflect the equipment's age?
- What policies are in place for determining the end of equipment life?

4.2 Company culture

The behaviour of directors and senior managers can strongly affect the culture within a company and consequently can influence the equipment it operates. A positive culture can be created through engagement, motivation and appreciation throughout the staff and supply chain.

Poor company culture can lead to failures.

Companies that are able to analyse will learn by their experiences and make corrections and improvements.

Providing good opportunities for communication ensures that the operators, maintainers and supervisors can meet and freely feed back to the management their concerns and ability to meet targets.

Industry networks and associations can be very effective for sharing experience.

4.2.1 Empowerment

Senior management exists to control, allocate and devolve certain responsibilities. Day to day operations and checks should be the responsibility of operators, maintainers or supervisors who (if correctly selected motivated and trained) thrive on having this responsibility. Senior managers should empower them to solve problems and make improvements within prescribed limits and following described practices; see 6.2: Roles and responsibilities.

4.2.2 Problem tagging

In a good organisation, all members of staff should have the incentive, encouragement, opportunity and responsibility for identifying and solving problems within their area of working/competence. They may not, however, appreciate the legal, technical, practical and financial limitations on solving the problem. Therefore staff need support through a local management chain to ensure modifications are practical, safe and recorded.

NOTE For additional information see EIGA publications on Human Factors [5]

4.3 Overview of integrity management throughout the plant lifecycle

4.3.1 Specification

Getting the original plant specification correct is key, so that the plant is designed to be suitable for the intended duty. Should any changes be made partway through the plant life they need to be suitable for the new duty.

4.3.2 Design

This is where the specification is translated into a physical detailed design that is fit for the intended duty.

4.3.3 Construction

The physical construction needs to meet the detailed design intent and there needs to be means to ensure this.

4.3.4 Commissioning / re-commissioning

It is essential to ensure that all equipment is working correctly before starting up the process. It is during start-up that a plant can see some of the most extreme transient operating conditions before settling into steady state conditions.

4.3.5 Operating life cycle and operating history

This forms the bulk of the ‘life’ of the asset, frequently lasting for decades. After the initial commissioning the brand new asset will enter service and be subject to operating loads.

Over years of service the asset will be examined and maintained and will age and deteriorate in condition. It is important to retain records of the operating history and problems encountered during the life.

4.3.6 Operational excursion and ad-hoc fitness for service inspection / assessment

Ideally, actual operating conditions will never exceed those originally envisaged at the specification stage. However this may not be the case, and operational excursions where the actual operating conditions exceed those for which the equipment was designed, e.g. temperatures and pressures beyond the design scope, and this can cause permanent damage.

Where an operational excursion has occurred, the owner / operator should consult with the competent person and jointly agree if a formal fitness for service assessment is required. This inspection is outside the normal schedule of inspections as specified in the formal periodic inspection scheme and it is designed to detect and assess whether or not the asset has been damaged as a result of the excursion.

The assessment should confirm:

- whether the equipment is fit for further service,
- whether the formal periodic inspection scheme needs updating to look at this damage more closely in future,
- whether the excursion(s) have 'used up' years of fatigue life etc.

4.3.7 Planned / reactive maintenance tasks / maintenance history

Routine 'Planned Preventative Maintenance' tasks are primarily designed to ensure the on-going availability of the asset. These will include 'servicing' and operator routine check sheets that form the lowest level of inspection. 'Reactive Maintenance' tasks are not performed routinely. This could be breakdown or other remedial works that have been found necessary to correct a problem.

Both planned and reactive maintenance tasks should build up a written maintenance history over months and years. These entries should be considered when reviewing a formal periodic inspection scheme as they can reveal on-going problems / failure modes with that asset.

4.3.8 Formal periodic inspection

A formal Periodic Inspection is a corner stone of an Integrity Management System. It should specify the minimum inspection and testing that will be carried out, how often, and any techniques that could be required. Before this can be developed, it is necessary to consider how the asset can degrade over time and which techniques can detect this.

Careful prior planning between all interested parties is required to complete inspections specified in a timely manner, minimising any plant downtime.

4.3.9 Inspection reporting

Reporting of the inspections is necessary to inform the operator, allow assessment of suitability for continued service and to build up a history for future reference.

4.3.10 Assessment of results and fitness for service declaration

Inspection reports should be assessed to determine whether the plant is fit to return to service and if so, for how long. These reports could have been produced by specialist contractors and unless the plant is 'as new'; it is likely that defects of varying severity will be reported. These defects should be assessed to determine whether they are of no consequence or require remediation.

4.3.11 Repair, re-rate or retire

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

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

When a repair is not technically possible or cost effective and re-rating is not possible, retirement of the asset could be the only option and to replace it with a new one. Any rerate shall be covered by a management of change process; see EIGA Doc 51, *Management of Change* [6].

4.3.12 Modification

There could be times during the life of the plant when it needs to be modified. The driver for this could be a desired process change or in response to revised best practice or regulation for that industry. Whatever the driver, it is important that the modification is subject to 'management of change' procedures [6], including appropriate risk assessments.

So that the modification is carried out correctly, the specification, design and construction steps discussed earlier should be reconsidered to ensure that the integrity of the plant is maintained. In addition, where the plant is subject to legislative essential health and safety requirements, the modification should also conform to this current legislation.

The modifications could require changes to the formal periodic inspection scheme and or schedule.

5 Inspection policy

An inspection regime is something which would be expected to cover the life of the plant or equipment, and be made up of several inspections / tests of the asset. Therefore careful thought and planning is required, particularly where the consequences of release are significant.

The main tool used in planning and specifying inspection / testing requirements is the formal periodic inspection scheme. However, there are several basic issues that need to be considered in order to identify the approach to planning and implementing an inspection regime and any testing techniques to be used.

Any local, regional or national regulations covering the inspection of equipment shall be also followed.

5.1 Objectives of inspection

The ultimate aim of an inspection regime is to ensure that the plant is safe. However, the specific objectives of any inspection or test could vary; therefore it is important to be clear about what an inspection regime is intended to achieve.

It could be expected to monitor damage from known degradation mechanisms or it could be required to guard against or identify an unexpected degradation mechanism. A combination of both could be the aim. Alternatively, a one off inspection could be required to provide information for a fitness for service assessment or to allow specification of a repair.

Whatever the objective, clear identification will help in determining the best approach to take.

5.2 Types of inspection

There is a range of inspection options available. Usually the more onerous offer greater benefit in terms of scope and detailed information gained. However the simplest of checks can still provide benefit and gain value from the ease and frequency with which they can be performed.

Commonly used options include:-

a) **Thorough internal inspection:** A detailed inspection from both the interior and exterior of the equipment. It is usually considered onerous because of the need to take the equipment out of service, clean and make safe and therefore the frequency of inspection can be an issue.

b) **Intermediate external inspection:** A detailed inspection but undertaken from the exterior only and therefore can sometimes be carried out when the equipment is still in service or at least without the requirements for internal cleaning and confined space entry. It is often used to supplement the less frequent thorough internal & external inspection, hence the term 'Intermediate'.

c) **Operator routines:** These usually only consist of brief checks on equipment condition at a very basic level. They can provide value as they are not considered onerous and therefore can be carried out on a regular basis, 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.

This list is not exhaustive, but provided only to illustrate that one cycle of an inspection regime may be made up of a combination of one thorough inspection, one or more intermediate inspections and many operator routines. Other specific types of inspection are described below.

5.3 Strategies for determining inspection interval

Where inspection intervals are not specified by regulation, there are a number of alternative approaches to determining the interval between inspections. One option is to use a prescriptive approach. This is based on guidance, produced for particular types of equipment, which gives recommendations for inspection intervals, for example, EEMUA 159 *Users' Guide to the inspection, maintenance and repair of above ground vertical cylindrical steel storage tanks* [7].

Another option is to carry out a 'Risk Based Inspection' 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 scheme. In an 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 any ways that these can be mitigated. If these mitigation processes include the examination of the equipment then an inspection scheme will be drawn up to define that inspection. The RBI can sometimes justify inspection methods that are more effective, less invasive and safer to implement than more conventional basic 'thorough' internal inspections. Guidance on Risk Based Inspection is given in API 580 *Risk Based Inspections* [8]

An alternative 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. It is important that there is a factor of safety in this method and the concept of half remaining life is commonly used. Examples of an evidence based approach can be seen in EEMUA 159 section 6 [7], and API 510 *Pressure Vessel Inspection Code: in-service inspection, rating, repair and alteration* [9].

Predicted degradation rates will usually be 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.

It is also possible to use a combination of approaches above.

5.4 Equipment age

The requirements for inspection can change through the equipment life. In the early stages it will 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 will also be required to test assumptions on active degradation mechanisms or verify predicted rates. This will lead to relatively shorter intervals between inspections, compared to later stages of its life.

As the equipment gains service history, experience of degradation will increase. If degradation assumptions can be verified, including predictability of rates, and service conditions remain within limits, it could be justifiable to extend service periods.

With further age, damage can begin to accumulate. Safety margins, such as corrosion allowance or remaining fatigue life, can reduce significantly. Degradation rates can increase, and overall confidence in the mechanical integrity will decrease. It would now be appropriate to reduce service periods between inspections. This is discussed in more detail in HSE Research Report RR509 section 3.4.1 [4]. Consequently, in addition to those mentioned in Section 5.2 of this document, the following types of inspection should be considered:

a) **Initial inspection (pre commissioning):** Normally carried out before plant or equipment is taken into service for the first time. This is used to assist in the establishment of the initial integrity of the asset.
b) **First inspection (post commissioning):** This inspection provides an early opportunity to identify any issues with the design, manufacture or installation, once the vessel has entered into service. The benefit of this inspection is greatest if the period between commissioning and the first in service inspection is restricted below that normally used for thorough inspections.
c) **Additional inspection:** An inspection made in response to a change of some form. This could be a modification to the plant or equipment, or a change in service conditions. Such a change in service could be either planned or as the result of an excursion beyond normal operating or design limits. The nature of the additional inspection will be dependent on the change that brought about the need for it.

5.5 Administration arrangements

Arrangements have to be made to support issues such as the scheduling of inspections and record keeping.

It will also be necessary to make decisions on who will carry out the inspection. This could be a combination of more than one person or organisation, especially where specialist techniques are used, or a range of types of inspection / testing.

5.6 Non-destructive examination techniques

The exact nature of the examination techniques to be used is a matter for consideration in formulating the formal periodic inspection scheme however, it is important that at an early stage the role of Non-destructive examination (NDE) is considered.

NDE has many uses and there is a wide variety of guidance available. Developing technology is extending the potential benefits. However, it is important to ensure the reliability of any technique used. Therefore, any new technique should be validated before adoption into part of the inspection regime.

6.0 Organisational arrangements for Integrity management

Careful thought needs to be given to the organisational arrangements for an integrity management regime. Whatever arrangements are in place for actually carrying out the inspection, it is likely that a team will be required to implement an effective integrity management regime. This is because a range of different disciplines and competencies will be required to bring in the required information and control the whole process from planning and execution through to decision making and review.

6.1 Competence

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

Inspection bodies shall be able to demonstrate competence.

NDE personnel shall be able to demonstrate training and competence. Certification can be achieved under either a central certification or an employer based scheme.

In addition to the formal arrangements for qualification and accreditation described above, it should be remembered that an effective integrity management regime will require consideration of all aspects of the potential degradation, inspection and assessment of the equipment involved. Therefore the team involved will require 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, where relevant, corrosion or metallurgy expertise); and
- Inspection techniques

Achievement of this will almost certainly require input from organisations or departments outside the inspection body. That is, at the very least, input of process specific knowledge from the site operational team.

A site operator using third parties in asset 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 a site operator uses in-house resources, it is equally important that there are means to ensure the competence of those involved.

6.2 Roles and responsibilities

Careful clarification of roles and responsibilities is required to ensure that the different parties involved in an integrity management regime will interact effectively, each role is filled by competent personnel and regulatory requirements are met. Arrangements also need to ensure independence of the inspection body from the site operating and production pressures.

6.3 Integrity assessment

It is important that following inspection an assessment of the integrity of the plant or equipment is undertaken. This is required to determine its fitness for continued service or otherwise, and could involve specification of conditions for continued service or repair. The responsibility for this task should be clearly allocated.

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

6.4 Site owner / operators

An inspection regime would normally form part of the demonstration that the operator of high hazard plant has taken all measures necessary to prevent major accidents and limit their consequences.

Specifically in terms of in-service inspection, the operator is required to ensure the plant is maintained in a safe condition. Whilst a site operator or employer could seek to rely on third party expertise to help ensure equipment integrity, they should be aware that the responsibilities allocated by legislation cannot be delegated.

Comprehensive management systems could be required, probably with implementation by a multidisciplinary team throughout the life cycle which would normally need access to site specific information and process knowledge to make informed technical decisions.

7 Formal inspection scheme

The formal inspection scheme is one of the most important documents associated with Asset Integrity.

It is used to define what examinations shall be carried out, when, by whom and how the results should be reported. It also specifies what preparatory work needs to be undertaken to allow the examination to proceed. It is, therefore, important that it is worded carefully and is prepared by one or more individuals with an extensive and detailed knowledge of the equipment and the processes contained within the plant.

The formal inspection scheme is an instruction to an inspector about what to look for during an inspection. This will always be the minimum acceptable and although the inspector can always request more, the inspector should not do less than is specified, unless it is in accordance with approved amendments to the scheme.

7.1 Content / scope of the inspection

The formal inspection scheme should contain, as a minimum, details on the nature and frequency of inspections, the measures necessary to prepare the system for inspection and include any inspections necessary before equipment is used for the first time.

7.2 Nature of inspection

It is important that during an inspection the inspector knows what to look for. Therefore the first stage in specifying the nature of the inspection should be to identify the anticipated modes of deterioration. This requires a detailed consideration of the substances and processes contained within the equipment and their effects on the materials of construction. Then the inspection necessary to detect and quantify the damage caused by this deterioration can be specified. In many instances a particular inspection technique will be the most suitable to detect specific deterioration.

It should be remembered that, although some modes of deterioration have been identified prior to the inspection, the inspector should always be prepared for other types of damage.

The nature of the inspection could include visual, internal or external and whether or not any special techniques such as NDE are required. The inspection of an item of process equipment will always have, as a minimum, a visual inspection of the external appearance of the containment looking for any signs of corrosion or other failure mechanism. This can often be supplemented by an internal inspection if a degradation mechanism affecting the inner surface has been identified.

Where the evaluation of the equipment determines that a periodic internal inspection is necessary careful consideration should be given to how this can be best carried out.

Certain equipment can be difficult and costly to prepare for internal access. There could also be confined spaces 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 need to be evaluated to determine whether they have equivalent capability of detecting the degradation mechanisms as would visual inspection.

Non-destructive examination can be required to, for example, measure the remaining wall thickness where corrosion or erosion might have removed some of the original material or examine for other signs of damage. In most cases the type of Non-destructive examination can, and should be specified in the formal inspection scheme. However it is important not to make the formal inspection scheme so specific that it reduces the freedom of the inspector to use a different technique if he considers it relevant.

7.3 Frequency

Inspections are carried on a routine basis with the frequency defined in the formal inspection scheme.

Where possible the anticipated rate of deterioration should be taken into account when determining the inspection interval.

It is considered good practice to select a short interval when the equipment is first commissioned; this can then be adjusted with experience. The principle of 'half-life' is often used to monitor age-related damage mechanisms. The rate of deterioration is calculated from measured changes in material thickness over time and extrapolated to find when that thickness will reach the minimum acceptable for safety. The next inspection is then set at half that remaining life.

If the time between inspections needs to be altered, for example if it is found that damage is occurring more or less rapidly than was expected, then the frequency will be changed and the Scheme updated.

7.4 Preparation for an inspection

It will often be impractical to carry out the inspection if the equipment is not prepared correctly. It is, therefore, important that the formal inspection scheme defines clearly all the steps that should be taken to prepare the equipment.

The scheme should concentrate on those details that might not be obvious to the operator and in particular those that can vary between inspections. For example if it is necessary to remove insulation to allow for the detection of corrosion under insulation the amount and location of the insulation should be made clear otherwise there is a risk that one area will be examined at every inspection rather than ensuring that a different area is considered each time.

In the planning and execution of the preparing works and of the inspections it is also necessary to use a procedure to ensure that potential hazards are identified and that vital precautions are not overlooked. Such a procedure requires formal and disciplined action in both the planning and execution of the work. This procedure should require a written statement to be signed by a responsible person prior to being issued to the individual responsible for performing the work. This would mean that the equipment is safe for work to commence and that risks are under control. Such a process is the core feature of a work permit system. For more information about a work permit system see EIGA doc 40 *Work Permit System* [10].

7.5 Inspection before putting into service

It can be important to undertake an inspection before equipment is put into service for the first time.

This inspection can ensure that the equipment has been designed and manufactured in accordance with all the relevant drawings and specifications. It can be used to allow material thickness measurements to be taken before any deterioration has taken place.

7.6 Review of inspection content/scope

As with any other working document the formal inspection scheme 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 scheme will have been used, possibly for the first time for a number of years. Reviewing the formal inspection scheme at this time allows the inspector who has just completed the inspection to make comments and to take account of his 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 formal inspection scheme. If this defect is as a result of an unexpected damage mechanism then it will need to be added to the formal inspection scheme along with the inspection necessary to look for it.

A formal inspection scheme should not be amended just before an inspection or test except to increase the scope, unless justified. This minimises the risk that the scope could be reduced to accommodate an operational problem.

8 Carrying out an inspection

8.1 Individuals involved

It should be understood that the periodic inspection itself will involve a number of parties, each having an important role to play in the success of the integrity assessment. They will include:

- The owner / operators of the equipment - this is likely to include representation from planning departments, production and procurement staff;
- The inspecting bodies themselves - for example, this could be the traditional Competent Person from user inspectorates, and third party organisations;
- Non-destructive examination contractors employed to carry out supplementary activities in support of the periodic inspection;
- Contractors employed to prepare plant for inspection - for example scaffolding, insulation or refractory contractors, tank or vessel cleaners etc. All of those identified above will need to establish and maintain effective methods of communication in order to carry out a suitable inspection programme.

8.2 Inspections during plant shutdowns

It is common within the process industries 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. It is important for the effective planning of a shutdown that sufficient time is allocated to the 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 round to establish general condition, or identify any obvious defects / deterioration;
- Detailed inspection in accordance with any existing formal inspection scheme - this to include any supplementary non-destructive examination activities;
- Whenever possible, time should be allocated in the shutdown programme 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. This could include 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 programme are effectively highlighted to the appropriate decision makers in the shutdown process; such issues could include:

- Inability to complete an inspection due to time or access restrictions – the inspector will need to clearly identify what affect this could have on establishing the suitability of plant for continued service;
- Inspections completed ahead of plan, this would need to be communicated in order to maximise the potential efficiency of any shutdown;
- Defects / deterioration that could require remedial work within a specified time;
- Defects / deterioration found that require immediate rectification; - It is important that this is highlighted so that the appropriate remedial action is taken.

9 Reporting of inspections

Following an inspection a report shall be issued by the person responsible for undertaking the inspection.

The purpose of the report is to clearly record the inspection stating, what has been done and give the results in the form of a condition report of that equipment. The report shall meet any special requirements laid down in the formal inspection scheme as well as being accurate and timely.

Typically the report will contain:-

- The name and address of the site, owner and operator (if different from the owner);
- The location of the equipment;
- Identification of the equipment with Piping and Instrumentation Diagram (P&ID), serial number and plant number;
- Full formal inspection scheme reference including version;
- Parts that were examined / not examined;
- What was exposed / what was not exposed;
- Type of inspection;
- Links to non-destructive examination reports;
- Condition of the equipment;
- Results of the inspection.

The results of the inspection shall be stated on the report along with other relevant details and information on the condition of the equipment. The results of inspection and tests on protective devices can be included if relevant to the condition of the equipment it protects

9.1 Report conclusions

The ability of the report to provide definitive conclusion on the fitness for service depends on the arrangements for making this decision. Common scenarios are:

a) Where there is a risk management team, the report should be presented to the risk management team who will consider the suitability for further service.
b) Where the responsibility for deciding if the equipment is suitable for further service has been agreed to be that of the inspecting competent person, then the report should go beyond being a condition report and where necessary report the serious defects which require attention immediately or within a time limit.

10 Post inspection integrity assessment

It is essential that all examination and testing findings, included within the subsequent reports, should be assessed by the integrity management team or individual(s) nominated by the team (hereafter called the assessor(s)). The assessor(s) could be staff employed by the operator of the equipment or can be a third party organisation. However, in all cases they should have the necessary competencies to carry out this review / assessment. The assessor(s) should be determined prior to the commencement of examinations.

The assessment is to provide for a final adjudication of the examination 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.

10.1 Assessment of deterioration

As part of the assessment, any deterioration identified during the examinations and tests should be considered. This can be within previously defined limits (e.g. corrosion allowance) and it would 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 structural integrity of an item of equipment for further service.

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

10.2 Change to subsequent examinations due to deterioration

Deterioration identified during the examinations should be fed back in to the formal inspection scheme to advise where future examinations 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 scheme for that equipment to reflect the deterioration identified elsewhere.

Where no deterioration is noted, this too can be fed back to the scheme. It is considered good practice to review schemes (or at least those parts of the appertaining to the actual examination) after each examination has been completed to ensure it remains suitable. The scheme should also reflect the age and condition of the equipment.

10.3 Assessment record

The documented assessment should include:

- A clear and unambiguous statement as to the equipment's on-going fitness for service.
- All deterioration is recorded.
- Prediction that current deterioration will remain within acceptable limits by the next inspection
- When future inspections should be carried out. This will normally be a calendar date but could also include additional parameters such as running hours, operational cycles, changes in process.
- Any limitations to the equipment's use.
- A statement that the formal inspection scheme continues to remain suitable or give details of any necessary changes required to the scheme.
- When the equipment is not considered suitable for further service then details of required repairs should be included.

10.4 Repairs

When repairs are considered necessary for the continued use of equipment then these should be carried out to recognized standards and specified date. The following documented information should be considered as a minimum and records kept:

- specify the repair;
- gain approval for the proposed design / method; and
- quality assurance requirements.

The information relating to the repair should be included and / or referenced within the final, documented review / assessment and the assessor(s) should confirm that the repairs are considered satisfactory.

10.5 Assessment of incomplete inspections

There could be instances when it is required to return equipment into service when all the required inspections contained within the formal inspection scheme have not been completed. This could be considered acceptable by the assessor(s) and if so documentation should be issued by them to highlight those outstanding inspection activities, the mitigation for non-completion and give timescales for their future completion.

10.6 Postponement of inspections

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

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

Should the formal inspection date have passed without carrying out an inspection an assessment should be made to determine whether the equipment should be immediately taken out of service or whether it is acceptable to complete an inspection at this stage. Additionally a review of the management system that allowed the date to be missed should be completed to identify any weaknesses in the system and measures taken to address any issues found.

11 Record keeping

As part of an integrity management system it is necessary for the operator to keep accurate, timely records, this ensures that decisions about the specific integrity of an individual piece of equipment can be easily traced and justified. This record keeping would normally be in the form of a technical file(s) applicable to individual items of equipment, and would be expected to contain the following information:

a) Documentation confirming the safe operating limit of the equipment;
b) Manufacturing information such as a data book including material information, welding information, testing information etc;
c) Details of the normal maintenance routine including reports of such;
d) Any reports of inspection/ testing;
e) Information pertaining to any repairs/modifications that have been carried out. (see point b) above);
f) The formal inspection scheme, including records of amendments;
g) Any information relating to any postponements;
h) Details of the operating conditions and the operating history of the item, for example how long has it been on certain duty, what duty was it on previously;
i) Any associated risk assessments, periodic reviews, ageing plant reviews;

j) Any other reports which contain information relevant to the assessment of safety.

While the above list will not be completely exhaustive it gives a good guide as to the type of information that could be required. It should also be noted that the extent of information usually available for differing types of equipment will vary: for pressure vessel it would be usual for all the above to be present, however historically the level of information that has been kept on pipework and storage tanks has, in certain circumstances, been less.

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

12 Integrity Management of Electrical, Control and Instrumentation (E/C&I)

This section is intended to provide guidance regarding technical and managerial issues surrounding ageing of Electrical, Control and Instrumentation (E/C&I) systems and equipment.

Any electrical, control or instrumentation system is potentially within scope if either:

- its purpose is to ensure that the plant or equipment stays within safe operating limits; or
- its failure could cause a dangerous situation.

Examples of such systems and equipment include:

- relays,
- switchgear,
- electric motors, (for example as part of back-up systems),
- starters,
- pressure, level and temperature sensors,
- transmitters,
- Programmable Logic Controllers (PLCs),
- Distributed Control Systems (DCS),
- Supervisory Control and Data Acquisition System (SCADA).

In safety systems, these systems and equipment are employed to provide emergency shutdown systems, trips, alarms etc., which either separately or in combination with other systems ensures safety in process plant, e.g. overfill protection systems for bulk storage tanks.

In terms of managing major hazards, it shall be clear which of these E/C&I systems are safety critical. This can be established through a variety of techniques including Safety Integrity Level (SIL) assessment, Hazard Identification (HAZID) and Hazard and Operability (HAZOP) studies and the identification of safety critical systems and the setting of performance standards for these

E/C&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 E/C&I specific degradation mechanisms. These include physical mechanisms such as:

- impact damage or surface abrasion,
- overheating/ burn damage,
- blockage,
- fouling or poisoning or the formation of ‘tin whiskers’ or dry joints, and instrumentation aspects such as instrument drift.

Poor quality control of plant painting activities can (as with mechanical plant) affect E/C&I equipment, for example the painting of flameproof glands, or painting over instruments.

There are also significant issues relating to the relatively shorter working life of E/C&I systems compared to some mechanical plant, and the degree to which some types of instrumentation and control systems, and the software that is used in them, can become obsolete or difficult to support.

On the other hand, software-based E/C&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.

Since the 1990s, international standards such as IEC/EN 61508 *Functional safety of electrical / electronic / programmable electronic safety related systems* [11] and IEC/EN 61511 *Functional safety – Safety instrumented systems for the process industry sector* [12] have provided a lifecycle-based framework for successfully deploying such systems and 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* [13].

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

For more information on the above, refer to HSE RR 823 [2].

13 Degradation mechanism

This section of the guide provides a brief introduction to the mechanisms that can lead to age related deterioration of plant, processes and equipment.

It is intended to provide concise and focussed information for non-specialists who are involved with the management of ageing plants and Regulatory Inspectors who could inspect ageing plant at major hazard facilities to help them understand the key issues and know what key indicators to look for.

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 however dry hot corrosion can take place in excess of 400 ^{o}C.
- General corrosion (a uniform loss of wall thickness) of pressure systems can be hazardous and result in potential catastrophic failure.
- Localised corrosion, pitting or crevice corrosion can be extremely damaging to a structure 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 catastrophic failure.

The presence of corrosion does not indicate that the equipment is not fit for service, just that the equipment is ageing.

Corrosion can be eliminated or reduced by material selection, protective coatings, cathodic protection, water treatments, system cleanliness, etc.

Corrosion can be accelerated by change of condition, temperatures, presence of contaminants, poor design. Rates of corrosion can be predicted at the design stage: it is typical to add a corrosion allowance on carbon steel systems.

13.2 Atmospheric corrosion

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

Similar to wet corrosion but generally at a lower rate unless pollutant levels are high for example in marine or Industrial (sulphate or nitrate) environment.

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 will become the anode and corrode. If the surface area of the steel is much larger than that of the aluminium the rate of loss of aluminium will be proportionately higher.

13.4 Erosion corrosion

Corrosion rates increase as a consequence of corrosion product layers being stripped away by high process flow conditions

13.5 Stress corrosion cracking (SCC)

A form of corrosion where a corrosive element such as a chloride is allowed to penetrate a material forming corrosion between material grain boundaries opened up by stress (for example cracking on the outer diameter of a pulled pipe bend).

Conditions for stress corrosion cracking are generally:- stress, the presence of moisture and a corrosive agent. The rate of corrosion will increase with temperature until moisture is no longer present.

Stainless steels (with chlorides) and brasses (with ammonia) are particularly vulnerable to SCC.

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 will typically form around and under items such as washers and bolts.

13.7 Fatigue

Reduction in material strength following the formation of cracks due to the effect of cyclical stresses over time.

Cracking due to fatigue is most likely to form at changes of section, such as nozzles where stress concentrations could be high.

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

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

13.8 Corrosion fatigue

Where the effects of fatigue from cyclical stresses are increased by the presence of a corrosive agent.

13.9 Erosion

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, increasing the leak rate; 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 collapse of cavitation bubbles. The energy directed into the material when the bubbles collapse can cause significant metallurgical damage and material loss. Examples are at pump inlet, at the discharge of a valve or regulator in two phase flow.

13.11 Carbon dioxide (sweet) corrosion

Corrosion as a result of dissolved carbon dioxide resulting in metal wall thinning and shallow pitting. Under high flow conditions deep elongated pits are sometimes observed. At temperatures typically above 80°C, an iron carbonate film can result in lower than expected corrosion rates.

13.12 Hydrogen sulphide (sour) corrosion

Corrosion as a result of dissolved hydrogen sulphide. The low solubility of the resulting iron sulphide results in the formation of a dark black film that protects the steel from even aggressive corrosion, however any break in the iron sulphide layer can result in very severe pitting.

13.13 Microbial corrosion

Corrosion as a result of bacterial contamination, commonly sulphate reducing bacterial (SRB). Microbial corrosion is typically in stagnant water, dead legs, bottom of tanks etc.

Requirements for microbial corrosion include:- bacterial life, sulphide, carbon, water, anaerobic condition, close to neutral pH, temperature for bacterial life.

13.14 Metal dusting

Type of high temperature corrosion occurring in the temperature range 400-800°C and in the hydrocarbon atmosphere (with high carbon activity). The degradation manifests itself in deposition of carbon on the surface of the metal, diffusion into its structure and growth of graphite grains what eventually leads to destruction of the material.

13.15 Creep

Time dependant deterioration at elevated temperatures in constant stress conditions resulting in potential wall thickness reduction and potential stress rupture.

13.16 Concrete degradation

The principal causes of concrete deterioration are settlement, erosion, cracking, and deterioration of concrete initiated by carbonation, attack by aggressive underground water, frost, chlorides, alkalis and acids.

Some mechanisms of concrete deterioration are:

- carbonation is a slow and continuous process which occurs when concrete reacts with CO2 from the air. It results in formation of calcium carbonate (CaCO3) and water;
- deterioration of concrete exposed to aggressive underground water 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;

To ensure suitability for service, all process plant concrete structures should be inspected periodically. If defects of the foundations of equipment are observed, an assessment should be carried out to establish the cause and extent of the defects and to predict future performance of the structure.

Monitoring and assessment are covered by EN 1504 Part 9 *Products and Systems for the protection and repair of concrete structures* [14].

14 Detection and sizing of defects and damages

14.1 Inspection procedures

An inspection is most effective if the potential damage mechanisms have been identified, locations where that damage is most likely to occur and methods to detect any significant defect are considered in advance of any inspection.

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. The summary is not meant to be exhaustive. For further information refer to HSE publication RR509 [4]

14.2.1 Visual

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 examiner.

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 corrosion. The equipment requires calibration, interpretation and often internal or external surface preparation. Basic digital thickness meters may not be sufficient for some inspections.

NOTE Any method used needs to take account of paint thickness.

14.2.3 Dye penetrant examination

Dye penetrant fluid is regularly used to detect cracking or other defects such as weld porosity.

A low viscosity coloured fluid is painted over the area for examination. After a period to allow the fluid to be drawn into any defect by capillary action, excess surface fluid is thoroughly cleaned away and a white (powder type) developer sprayed over the area under examination. The developer draws out any dye penetrant fluid that has penetrated any defects identifying the location and size of the defect.

This method is simple but requires a competent operator for correct interpretation and can give false positives. 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 which are looking for defects that have developed in service. However, this is not effective on surfaces that have been painted, even if the paint has been removed.

14.2.4 Ultrasonic detection (UT)

Ultrasonic equipment is commonly used for identifying crack-like indications in pressure systems.

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 which are looking for defects that have developed in service.

14.2.5 Magnetic particle inspection (MPI)

Magnetic particle inspection is regularly used to detect cracking on magnetic (carbon steel) pressure equipment.

A hydrocarbon based fluid containing iron powder is sprayed over the area for examination and a magnetic field applied. The strength of the magnetic field increases across any cracks and the iron powder is drawn to this location giving a visual indication of the defect.

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

14.2.6 Eddy current examination

Eddy current examination applies an alternating current through a small hand held probe. The current strength is affected when the probe passes over any cracks in a metal surface. This is typically indicated by a ‘flick’ of a meter needle. This technique is effective on non-ferrous materials, such as aluminium and austenitic stainless steel. It can pick up cracks in compression sometimes missed by dye penetrant examination

14.2.7 Radiography

Radiographic examination (X-ray or Gamma ray) is an industry standard method for examining, approving and recording new construction welds. Radiography is particularly good at identifying voids, inclusions, lack of fusion, poor weld profiles etc. It is less useful for detecting in service defects such as cracking.

14.2.8 Thermography

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.

For EIGA documents refer to: European Industrial Gases Association, 3-5, avenue des Arts, 1210 Brussels. www.eiga.eu

[1] *Directive 2003/105/EC of the European Parliament and of the Council of 15 December 2003 amending Council Directive 96/82/EC of 9 December 1996 on the control of major accidental hazards involving dangerous substances;* www.eur-lex.europa.eu

[2] RR823 *Plant Ageing Study – Phase 1 Report*, prepared by ESR Technology Limited for the Health and Safety Executive 2010; www.hse.gov.uk

[3] EEMUA 231, *The Mechanical integrity of plant containing hazardous substances*; Engineering Equipment & Materials Users' Association, 63 Mark Lane London EC3R 7NQ; www.eemua.org

[4] RR509 *Plant Ageing – Management of equipment containing hazardous fluids or pressure*, prepared by TWI Ltd, ABB Engineering Services, SCS (INTL) Ltd and Allianz Cornhill Engineering for the Health and Safety Executive, 2006; www.hse.gov.uk

[5] EIGA Human Factor Safety Information series, in particular: HF-01 *Human Factor Overview;* Safety Info HF-02 *Individual Training and Competence;* Safety Info HF-05 *Task Maintenance Errors* www.eiga.eu

[6] EIGA Doc 51 *Management of changes* www.eiga.eu

[7] EEMUA 159, *Users' Guide to the Inspection, Maintenance and Repair of Above ground Vertical Cylindrical Steel Storage Tanks*; Engineering Equipment & Materials Users' Association, 63 mark Lane London EC3R 7NQ; www.eemua.org

[8] API 580 *Risk-Based Inspection*, American Petroleum Institute, API Publishing Services, 1220 L Street, NW, Washington, DC 20005, www.api.org

[9] API 510 *Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration*; American Petroleum Institute, API Publishing Services, 1220 L Street, NW, Washington, DC 20005, www.api.org

[10] EIGA Doc 40, *Work Permit System* www.eiga.eu

[11] IEC/EN 61508-5, *Functional safety of electrical / electronic / programmable electronic safety-related systems, Part 5: Examples of methods for the determination of safety integrity levels*; CEN European Committee for Standardization, rue de Stassart 36, B-1050 Brussel www.cen.eu

[12] IEC/EN 61511, *Functional safety – Safety instrumented systems for the process industry sector*; CEN European Committee for Standardization, rue de Stassart 36, B-1050 Brussel www.cen.eu

[13] EEMUA 222, *Guide to the Application of IEC 61511 to safety instrumented systems in the UK process industries*; Engineering Equipment & Materials Users' Association, 63 mark Lane London EC3R 7NQ; www.eemua.org

[14] EN 1504-9, *Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity - Part 9: General principles for the use of products and systems*; CEN European Committee for Standardization, rue de Stassart36 , B-1050 Brussel

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

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

Appendix 1: Cryogenic coldbox located pressure equipment

The industrial gases industry generally does not carry out periodic inspection of cryogenic process vessels and associated pipework located within a coldbox.

This policy has been established over many years, based on operating experience, the inherently stable and benign conditions within an operating cryogenic plant and an absence of the traditional failure mechanisms for such equipment:- namely corrosion, erosion, fatigue.

An annual inspection should be carried out to check for coldbox cladding deterioration and purge gas system deterioration that might allow ingress of moisture and degradation mechanisms to develop. The annual inspection should give confidence that the environment within the coldbox is dry, inert and that there are no obvious indications of cryogenic and/or pressure leaks.

Should an opportunity arise (such as insulation removal for repair) an ‘opportunity examination’ of coldbox located equipment should be carried out.

The practice of ‘no periodic inspection of coldbox located pressure equipment is supported by the arguments that:-

- Cryogenic plant is constructed from materials that have low corrosion potential. These materials retain their corrosion resistance at temperatures below ambient and experience shows that corrosion at cryogenic temperatures. is negligible
- The process fluids are dry, clean and non-corrosive.
- Design and construction is carried out to well established and internationally recognised codes and standards. Designs take into account pressures, loadings, temperature changes and movements expected during normal running and during startup and shutdown. The designs also take into account that vessels and associated piping will be largely inaccessible within a ‘coldbox’.
- The operating mode of a cryogenic air separation plant is generally ‘steady state’ with few pressure and temperature variations.
- The materials used in the construction have high fracture toughness characteristics. The critical defect size, for the initiation of an unstable fracture, would allow a defect to be detected well before the critical defect size is reached, from an increase in coldbox pressure or from the presence of cold patches.
- The 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.

Inspection procedures and report form pro forma are attached for guidance.
The annual 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* [15]

- Report 1 Annual external inspection
- Report 2 Opportunity inspection

Report 1: Annual external inspection

Report 1: Coldbox Located Pressure Equipment Annual Inspection			
#	**Inspection Item**	**Condition Found**	**Remedial Actions (if required)**
1	Check for ice build-up on the cold box skin, and where valves and pipework penetrate the coldbox. Where ice build-up is found: • compare extent with previous inspections or plant operator reports with consideration of the time of year or ambient temperature. • determine and record the cause of the ice-build up, whether it represents a hazard to internal equipment or the coldbox structure, and any remedial action required. *Note: Pay particular attention to new patches or patches that engulf carbon steel structural beams*		
2	Where ice patches are of a size where they could represent a danger to personnel or equipment should they detach (for example following a plant trip), appropriate precautions shall be implemented, for example: • Install scaffold platform • Cordon off the area • Provide warning signs		
3	Check for cracks in the cold box skin and on structural beams. Where cracks are found: • compare size and location with previous inspections or plant operator reports; • determine and record the cause of the cracks; • determine whether there is a risk of loss of perlite or whether a hazard exists to internal equipment or the cold box structure; • determine any remedial action required.		
4	Check for significant corrosion on the cold box structure, any externally mounted spring hangers and holding down bolts. *Note: Pay particular attention to any beams and columns on the underside*		

Report 1: Coldbox Located Pressure Equipment Annual Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	of the box where maintenance of paint integrity is harder to ensure. *Ensure there is no wet debris in contact with significant carbon steel supports.*		
5	Check interspace purge for adequate flow-rate. *Note: each entry point shall indicate a flow.* Check operator reports to confirm interspace flow has been maintained.		
6	Check that nitrogen purge feed pipework is protected against corrosion and that the integrity of the pipework is maintained.		
7	Check cold box purge gas pressure and oxygen % from analysis tapping at roof level (and if considered necessary at other points).		
8	Check cold box interspace pressure monitoring switches or transmitters for correct signal, value, tagging and alarm set point. Ensure their location is known to operators.		
9	Check all interspace overpressure protection devices. Check that they are included on the P&ID and are periodically examined. Check any cold box interspace deadweight or hinged flap pressure relief devices for correct marking, positioning, or signs of recent lifting. Visually check any side mounted blow-out discs are in place and free from ice build-up. *Note: If close access is not possible the check may be carried out from ground level or other position with the use of binoculars.*		

Report 1: Coldbox Located Pressure Equipment Annual Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
10	Check process pressure relief valves for correct marking, positioning, and freedom from ice build-up, leakage, or signs of lifting.		
11	Check for potential water ingress points through man-way covers, cover gaskets, corrosion through carbon steel cladding, split valve boots etc. Check for evidence of excessive steam usage (e.g. to thaw ice patches on valve boxes). *Note: Any moisture ingress to cold box can result in frozen wet perlite which can constrain and damage pipework*		
12	Check valve spindle penetrations for indications of contact with the cold box structure. Record any such examples and determine the significance and any remedial action.		
13	Check that internal vessel nameplates are readable and securely displayed on external face of the cold box.		
14	Check that access ways, roofs, handrails, access ladders, cages, platforms, kick-plates are all in a safe condition.		
15	Check and record integrity of pipe lagging, field pipework, instrumentation etc. Consider the following: • paint condition; • insulation in good order and weather sealed; • no deposits on surface of pipework If significant corrosion found, carry out an ultrasonic thickness survey of the corroded pipework.		
16	Check perlite level and top up as required. (If the addition of perlite is more than would be considered due to compaction further investigation could be required)		

Report 1: Coldbox Located Pressure Equipment Annual Inspection			
#	**Inspection Item**	**Condition Found**	**Remedial Actions (if required)**
17	Review plant operator report records since last cold box inspection, and any adverse issues raised.		
18	Check the plant has adequate written thawing and start-up procedures.		

Report 2: Opportunity inspection

Report 2: Opportunity Inspection of Cold Box Located Pressure Equipment			
	Inspection Item	**Condition Found**	**Remedial Actions (if required)**
1	Visually examine external surfaces of pipework, pressure vessels, heat exchangers and valves for cracks, corrosion, damage or deterioration. *Note: Where appropriate, NDT methods such as dye-penetrant, ultrasonic or eddy current techniques should be used.* Pay particular attention to: • welded areas and changes of section for cracks; • potential presence of perlite scouring damage; • instrument lines where they connect to vessels or pipework that could have become deformed; • potential pipework corrosion due to wet insulation, particularly under metal banding; • high pressure pipework; • austenitic stainless steel vessels and pipework local to possibly moist slag wool insulation due to the potential for stress corrosion cracking.		
2	Where possible, visually examine internal surfaces of cold box cladding for signs of water ingress that could indicate flaws in the cold box jacket.		
3	Examine cold box structural framework for deterioration or cracking due to cryogenic leaks.		
4	Examine pipework hanger condition and their attachment points to equipment and structures.		
5	Visually examine the internal purge gas distribution pipework. Check for indication of blockages to vent holes or loss of any hole protecting filter cloth		

Report 2: Opportunity Inspection of Cold Box Located Pressure Equipment			
	Inspection Item	**Condition Found**	**Remedial Actions (if required)**
6	Carry out a leak test of the coldbox located pressure equipment, if possible. *Typically at 0.5barg*		
7	When applicable, significantly modified or repaired coldbox equipment shall be subjected to non-destructive testing (NDT) in accordance with the design code.		

Appendix 2: Cryogenic bulk storage tanks

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

This policy has been established over many years, based on operating experience, the 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, fatigue.

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.

It is recommended to 'revalidate' storage tanks at intervals not exceeding 20 years.

In the industrial gases industry a revalidation is sometimes recommended for equipment with a long expected lifetime where that equipment is not subject to periodic internal inspections due to the absence of the traditional failure mechanisms such as corrosion, erosion, fatigue.

A revalidation will typically include:-

- Design and document review
- Service history review
- External inspection review including previous reports, relief valve inspections etc.
- Revalidation statement

Where a satisfactory condition cannot be recorded against each of the revalidation items, an internal inspection may be considered necessary.

The practice of 'no periodic internal inspection of cryogenic storage tanks is supported by the arguments that:

- Cryogenic storage tank inner vessels are constructed from materials that are corrosion resistant. These materials retain their corrosion resistance at temperatures below ambient and experience shows that corrosion at cryogenic temperatures is negligible;
- The process fluids are dry, clean and non-corrosive;
- Design and construction is carried out to well established and internationally recognised codes and standards. Designs take into account pressures, loadings, temperature changes and movements expected during normal running and during startup and shutdown. The designs also take into account that inner tank and associated piping will be largely inaccessible within an outer jacket;
- The operating mode of cryogenic storage tanks is generally 'steady state' with few pressure and temperature variations;
- The materials used in the construction have high fracture toughness characteristics. The critical defect size, for the initiation of an unstable fracture, would allow a defect to be detected, well before the critical defect size is reached, from an increase in interspace pressure or from the presence of cold patches;
- The 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.

Inspection procedures and report form pro forma are attached for guidance.

The annual inspections include actions to manage the risks from overpressure and overfilling which might 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* [16]

Report 3 Annual external inspection
Report 4 Revalidation

Report 3: Annual external inspection

Report 3: Bulk Storage Tank Annual External Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
1	Check for ice build-up on tank outer jacket and on valve boxes. *Note: Pay particular attention to any new ice build-up.* Where ice build-up is found: • compare extent with previous inspections or plant operator reports with consideration of the time of year or ambient temperature. • Determine the cause of the ice-build up; • Record whether it is indicative of an internal product leak, interspace gas leakage or 'cold conduction' due to poor insulation (such as on valve boxes where insulation has become wet); • Identify any remedial action required.		
2	Check for cracks on the tank outer jacket and on valve boxes. *Note: Pay particular attention to areas where cold pipework penetrates the carbon steel jacket, such as pressure safety valve and vent pipework.* Where cracks are found: • compare size and location with previous inspections or plant operator reports; • determine and record the cause of the cracks; • determine whether there is a risk of loss of perlite or possible loss of support to equipment such as pressure safety valves; • determine remedial action required.		
3	Check for significant corrosion on the tank outer jacket and supports. *Note: Pay particular attention to relief valve or vent pipework supports where the environment could be continually wet and maintenance of paint integrity is harder to ensure.*		

Report 3: Bulk Storage Tank Annual External Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
4	Check pressure safety valves for: • audible leak tightness; • freedom from permanent icing; • evidence of recent lifting; • adequate support; • unobstructed and safely directed outlets; • identification and marking; • Current 'in test' date.		
5	Check interspace purge system for correct functioning: • check and record the purge gas flow meter reading and if available, inlet pressure; • check operator reports to confirm interspace flow has been maintained; • check purge pipework is protected against corrosion and that the integrity of the pipework is maintained.		
6	Check interspace pressure and oxygen % analysis at roof level (and if considered necessary at other points). • check and record the %O2 in the interspace gas at the top of the tank from a roof located tapping point to confirm no ingress of atmospheric air. check and record the interspace pressure at the top of the tank from a roof located tapping point.		
7	Check any interspace pressure monitoring switches or transmitters for correct signal, value, tagging and alarm set point. Make sure their location is known to operators.		
8	Check interspace overpressure protection devices for correct marking and signs of recent lifting. Check that they are, included on the P&ID and subject to periodic		

Report 3: Bulk Storage Tank Annual External Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	inspection in accordance with a procedure and within their test date.		
9	Check and record details of level measurement device(s), including settings and functions of high alarms *Note: Typically at 95% with possibly additional secondary set point at 98%.* Check that they are 'in test' and included on the P&ID *Note: At intervals not exceeding 24 months ,tank liquid level device(s) shall be examined in accordance with a procedure*		
10	Check any overflow deadweight valve or overflow control valve for signs of recent function and freedom from obstruction. Check that the deadweight valve or control valve system is in 'in test', included on the P&ID and subject to periodic inspection to a procedure *Note: At intervals not exceeding 24 months any overflow control valve and its full loop must be examined in accordance with a procedure*		
11	Check and record details of any overfill detection device(s) such as low temperature detection in overflow line or High differential pressure level measurement (where no overflow line exists). *Note: At intervals not exceeding 24 months any overfill detection device shall be examined in accordance with a procedure.*		
12	Check function of emergency shut off valves: • initiate closure of valve actuator; • confirm the actuator strokes fully and smoothly and any limit sensors indicate correctly; • check that there is minimal liquid flow from the outlets of		

Report 3: Bulk Storage Tank Annual External Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	each of the ESOVs following venting of downstream pipework liquid inventory. *Note: It is recommended that valve closure tests are initiated by different emergency buttons on a rotation basis.*		
13	Check and record details of pressure control and pressure raising valves. Record date of last calibration.		
14	Check integrity of tank supports and outer jacket structure: • check concrete plinth and outer jacket for ice patches; • check concrete legs and plinth for cracks, deterioration and signs of settlement; • check the condition of any inner vessel holding down bolts, plates and nuts that protrude from the underside of the concrete plinth; • check condition of the paint coating, particularly where corrosion is likely to affect the structural integrity.		
15	Check for potential water ingress points on valve box access cover plates, valve spindle penetrations.		
16	Check that access steps, handrails, platforms, kick-plates are all in a safe condition.		
17	Check and record integrity of pipe lagging, field pipework, instrumentation etc. Consider the following: • paint condition; • insulation in good order and weather sealed; • no deposits on surface of pipework; • if significant corrosion found, carry out an ultrasonic thickness survey of the corroded pipework.		
18	Check perlite level and top up as		

Report 3: Bulk Storage Tank Annual External Inspection			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	required. (If the addition of perlite is more than would be considered due to compaction further investigation could be required)		
19	Check the tank is clearly labelled with product, any required warning signs and useful information for example volume.		
20	Check tank nameplate is attached and that the tank is being operated within the design limits.		
21	Review plant operator reports since last tank inspection, and any adverse issues raised.		

Report 4: Revalidation

Report 4: Bulk Storage Tank Revalidation			
#	**Inspection Item**	**Condition Found**	**Remedial Actions (if required)**
1.0	DESIGN REVIEW Review design documentation (e.g. from original construction drawings and nameplate details)		
1.1	Establish that the essential design information is complete to the satisfaction of the Competent Person.		
1.2	Confirm that the design and construction was approved and witnessed by the Competent Person.		
1.3	Confirm that any modifications have been correctly designed and approved and have been implemented properly. 1		
1.4	Consider the implication of changes in environmental standards (e.g. wind, earthquake and siting of adjacent facilities,		
1.5	Review proposed changes in service conditions.		
1.6	Assess the consequences of operational excursions outside the design limits identified in the service history review.		
1.7	Review of tank against EIGA requirements Compare tank details including instrumentation, protective devices, siting against requirements in EIGA Doc 127 [16]		
1.8	Review pressure vessel relief requirements Review the current over and under pressure control and relief calculations and physical execution. The review shall include sources of over and under pressure, sizing of appropriate relief devices and piping, verification of correct		

Report 4: Bulk Storage Tank Revalidation			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	installation.		
1.9	Review service history. Where available the following information shall be reviewed: • changes of service • previous corrective action/rectification reports • reports of operational problems • reports of ice build-up and analysis of cause • reports of under or over pressure excursions and corrective actions • periods and condition when out of service • maintenance records • review the service and maintenance history. Consider whether these are sufficient to confirm that the tank has operated within its design envelop within a dry and inert environment.		
2.0	GENERAL INSPECTION		
2.1	Overall external visual assessment Carry out an overall visual inspection of the outer jacket, looking for signs of leaks, or insulation underperformance. Look in particular for indications of cold patches, cold bands, or areas of condensation. Any such areas should be the focus for the further inspection procedures outlined below.		
2.2	Purge system inspection Check the Interspace purge pressure and flow control devices. Confirm these are fully functional.		
2.3	Interspace purge analysis		

Report 4: Bulk Storage Tank Revalidation			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	Take a sample of the interspace purge gas at low and high level to confirm no atmospheric air (typically <0.5% O_2).		
2.4	Insulation condition Perlite condition can be assumed to be acceptable if the tank has no significant ice patches or bands on the outer jacket. Should jacket penetrations, ice bands or history indicate that the insulation could contain moisture, consider the requirement to carry out perlite sampling at four locations at low level within the interspace. Samples shall be taken by inserting a hollow tube (or similar dedicated sampling device). Perlite samples removed shall be placed in re-sealable plastic bags with markings indicating the location and depth of the samples. The general condition and moisture content of the insulation shall be confirmed by laboratory means. *Acceptance Criteria:- The insulation shall be deemed acceptable if it is not noticeably wet.*		
2.5	Emergency shut-off valve function Carry out a functional inspection of internal or external emergency shut off valves. *Inspection should confirm freedom of movement of actuator spindles.* A residual leakage test shall be carried out on each closed valve by opening a downstream valve or drain valve to confirm acceptable tightness.		
3.0	STRUCTURAL REVIEW		
3.1	Outer jacket condition Visually examine the external surfaces of the outer jacket and attachments for corrosion,		

Report 4: Bulk Storage Tank Revalidation			
#	Inspection Item	Condition Found	Remedial Actions (if required)
	cracking or other forms of mechanical damage with particular attention to areas under any ice patches. Supplement the inspection with other NDT techniques as necessary. Examine and record the paint condition.		
3.2	Concrete plinth and column condition Visually examine the external surfaces of the concrete plinth and columns for cracks, degradation or other forms of mechanical damage with particular attention to areas under any ice patches. Apply any additional specialist inspection techniques considered necessary such de-lamination, carbonation test etc. (see EN 1504-9 [14])		
3.3	Settlement of the civil foundations The civil foundations of the tank shall be examined to establish continued fitness for purpose. *Note: Of particular concern is any evidence of uniform or differential subsidence or degradation of the concrete pile caps.*		
3.4	Ladder, access platform, handrail and walkway condition Carry out a visual inspection of all ladders, access platforms, handrails and walkways. Supplement the inspection with other NDT techniques as necessary.		