The ageing in major risk process plant: review of the approaches with a glance to the Seveso III Directive

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Abstract

The degradation of process plants due to ageing-related mechanisms such as corrosion, erosion and fatigue is becoming a key issue at a worldwide scale, where the life span of process plants, mainly for economical reasons, is prolonged well beyond the expected life extent.
Despite its increasing importance, ageing issues are rarely incorporated in the Management System, neither in the SMS of major risk installations. This is to a large extent due to the absence of a governing legal framework, which otherwise exists for offshore facilities, power plants and nuclear plants.
This lack of regulation is partially covered within the Seveso III regulation, where the analysis of the process plant and equipment ageing is explicitly required within the Safety Management System. The underlying concepts, available approaches and techniques to facilitate the development of this SMS section are discussed in this paper.

Keywords: Ageing of process plant, major risk installation, Seveso Directive

1. Introduction

The degradation of process plants due to ageing-related mechanisms such as corrosion, erosion and fatigue is becoming a key issue at a worldwide scale, where the life span of process plants, mainly for economical reasons, is prolonged well beyond the expected life extent. The average estimated design life of a typical process plant is about 25 years, but, on the other hand, onshore process plants are continuously maintained and repaired as soon as ageing of assets is observed.
As far as offshore facilities are concerned, the applied methodology for lifetime extension is subject to a severe regulatory scheme, starting with a condition assessment and gap analysis (legal requirements and other requirements), and subsequently a criticality screening followed by risk assessment & risk mitigation to

justify for life extension. This approach is similar to the one applied in the nuclear industry; in both business areas the design lifetime is well defined upfront, after which a decommissioning takes place. An extension of lifetime can be considered only after a thorough assessment of the asset integrity and compliance considerations pertaining to the new extended life.
In the process industry this same logic does not fully apply and the inspection regime imposed by authorities is rather limited.

On the other hand, the relationship between ageing assets and major incidents has been recently examined (HSE, 2006). The analysis of the accident reported in 3 main databases for major incidents reporting (MARS, RIDDOR and MHIDAS) brought the Health & Safety Executive to conclude that plant ageing does constitute a threat to health and safety performance of hazardous installations onshore: within the uncertainties of the review, a reasonable statement to describe the size of the ageing issue is that "approximately 60% of major hazard loss of containment incidents are related to technical integrity issues and, of those, 50% has ageing as a contributory factor". It therefore concluded that plant ageing mechanisms are a significant issue in terms of major hazard accidents.

Despite its increasing importance, ageing issues are rarely incorporated in a company Management System. This is to a large extent due to the absence of a governing legal framework, which otherwise exists for offshore facilities, power plants and nuclear plants (Candreva & Houari, 2013).
This lack of regulation is partially covered within the Seveso III regulation, where the analysis of the process plant and equipment ageing is explicitly required within the Safety Management System, that in the Annex III requires the: "*management and control of the risks associated with ageing equipment installed in the establishment and corrosion*", despite the quantification of the ageing effects within the risk analysis is still not required (Seveso III, 2012).

1.1 Underlying concepts

The Health & Safety Executive (HSE, 2006) describes ageing and ageing plant as follows: "ageing" is not about how old equipment is; it is about its condition, and how that is changing over time. Ageing is the effect whereby a component suffers from material deterioration and damage (usually, but not necessarily, associated with time in service) with an increasing likelihood of failure over the lifetime. Overall, "ageing plant" refers to a plant that is, or may be, no longer considered fully fit for purpose due to age-related deterioration in its integrity or functional performance.

Many systems, which may be subject to ageing, can contribute to the health, safety and environmental performance of plant, or could compromise the plant performance in case they should fail or collapse. Four main categories can be used to classify the critical asset types:

- Primary containment systems – static and moving elements of the process, as piping, vessels, etc.
- Control and Mitigation Measures, i.e. process safeguards

- EC&I Electrical, Control and Instrumentation systems and equipment - including: relays, switchgear, electric motors, sensors and transmitters, PLCs, DCS, valves, pumps, etc.
- Structures – e.g. supporting structures, civils features and foundations

Figure 1 shows a summary table of the ageing mechanisms affecting the different critical assets.

Ageing Mechanism	Primary Containment	Structures	Safeguards	EC&I
Corrosion	✓	✓	✓	✓
Stress Corrosion Cracking	✓	✓	✓	
Erosion	✓	✓	✓	✓
Fatigue	✓	✓	✓	
Embrittlement	✓	✓		✓
Physical damage	✓	✓	✓	✓
Spalling		✓		
Weathering		✓	✓	
Expansion/ contraction due to temperature changes (process or ambient) or freezing	✓	✓	✓	✓
Instrument drift				✓
Dry joint development				✓
Detector poisoning				✓
Subsidence		✓	✓	

Figure 1. Ageing mechanisms affecting the different critical assets

2. Management of plant ageing

In order to include plant ageing in a well structured Health, Safety and Environment Management Systems (HSEMS) ageing issues should be taken into account in the management of system operations, covering all the above listed asset types.
The identification and management of ageing plant issues in relation to process safety is recognised in a number of key risk control systems, which must be identified and documented in order that they are regularly reviewed and updated.
Keeping into account the contents of SMS defined in the Seveso III, the plant ageing could be taken into account as detailed in Table I.

Table I. Ageing issues within a Safety Management System

Elements of a SMS	Plant ageing issues
(i) organisation and personnel — the roles and responsibilities of personnel involved in the management of major hazards at all levels in the organisation, together with the measures taken to raise awareness of the need for continuous improvement. The identification of training needs of such personnel and the provision of the training so identified…	• Training and Competence development • Responsibilities and Communications
(ii) identification and evaluation of major hazards — adoption and implementation of procedures for systematically identifying major hazards arising from normal and abnormal operation including subcontracted activities where applicable and the assessment of their likelihood and severity;	• Risk Assessment processes in terms of possible initiating events, concurrent causes, domino effects propagators.

Elements of a SMS	**Plant ageing issues**
(iii) operational control — adoption and implementation of procedures and instructions for safe operation, including maintenance of plant, processes and equipment, and for alarm management and temporary stoppages; … management and control of the risks associated with ageing equipment installed in the establishment and corrosion; inventory of the establishment's equipment, strategy and methodology for monitoring and control of the condition of the equipment;	• Maintenance Management Systems • Asset Management and Integrity Systems to identify HSE Critical plant and equipment • Clearly identified and accessible Asset Register documentation to ensure action is taken at the correct intervals. • Permit to Work • Audit and Inspection regimes
(iv) management of change — adoption and implementation of procedures for planning modifications to, or the design of new installations, processes or storage facilities;	• Management of Change procedures
(v) planning for emergencies	
(vi) monitoring performance — adoption and implementation of procedures for the ongoing assessment of compliance with the objectives set by the operator's MAPP and safety management system, and the mechanisms for investigation and taking corrective action in case of non-compliance.	• KPI
(vii) audit and review — adoption and implementation of procedures for periodic systematic assessment of the MAPP and the effectiveness and suitability of the safety management system;	

2.1 Responsibilities and training and competence development

Managing equipment in general requires a wide range of competencies. But, considering the problem related to the ageing requires also to deepen the knowledge about the structures.

Competence is key to the management of ageing issues. Suitably competent people need to be employed in inspection and assessment activities, making any necessary judgments about remaining life (especially for equipment and components which cannot be inspected), defining remediation programmes and additional risk reduction, and making assessments in support of life extension.

Competence is both having and demonstrating the necessary knowledge, skills and experience to do a specific task within a particular context. Employers need to have sufficient knowledge to appreciate and employ the range of competencies required, and to maintain adequate control. Depending on the size of organisation and the type of equipment, the key competencies may be contained in-house, or accessed from sub-contractors and consultants.

The key competencies required to manage equipment should be integrated with the knowledge of equipment and structures ageing mechanism, management and mitigation:

- Education and training in industrial engineering.
- Understanding of the relevant regulatory requirements and any approved code of practice and guidance for the equipment
- Knowledge of design and construction codes and practices.

- Familiarity with the equipment concerned, together with the detail of the design and materials of construction, and the operation and maintenance requirements.
- Understanding of the metallurgical issues for the construction materials and the effect of environment so as to predict and/or prevent potential damage mechanisms.
- The knowledge and ability to plan inspection and maintenance to ensure safety.
- Experience of plant inspection, inspection techniques and NDT, and knowledge of their applications and limitations.
- The knowledge and ability to undertake routine maintenance tasks and to know when to refer to specialist contractors.
- Experience of welding, both practical skills and welding engineering.
- The management skills for organising and ensuring necessary actions take place.
- Teamwork skills and understanding the roles of others.
- The communications skills to ensure that the operational knowledge is spreaded among relevant operators and managers.

The team of managers, supervisors and technicians that is responsible for the equipment must have these competencies and be organised in a way that utilises them in the roles they undertake.
It is now common good practice for organisations to define the responsibilities of the different roles within an organisational structure. This leads to a statement of the competencies required for particular jobs and roles at all levels of responsibility, from technicians to managers.
Creating an underlying Key Competencies List for both Technicians and Managers focuses the mind on whether to train-up or buy-in what is needed.
Competencies may be demonstrated by proven experience or by having suitable technical qualifications, dependent on the level appropriate for technicians, supervisors and managers.

2.2 Risk assessment

In the risk assessment procedure, the general scheme in Figure 2 can be applied, starting from the definition of technological risk as a product of probability of an accident and severity of the consequences deriving from the event.

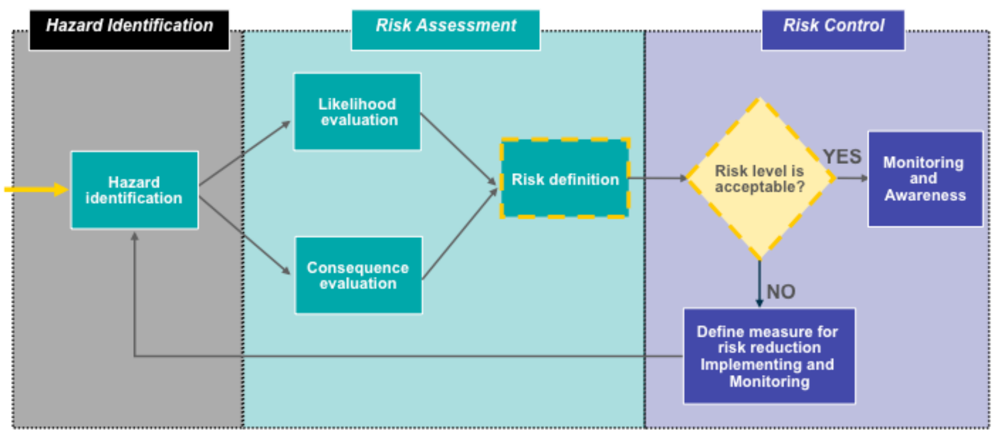

Figure 2. Risk assessment procedure

The ageing of plant and equipment will be certainly to be considered qualitatively in the hazard identification phase in terms of:

- possible initiating events,
- concurrent causes,
- domino effects propagators

With respect to the probability of occurrence of Top Events, the degradation of the behaviour of the components due to ageing can be assessed borrowing the methodologies and approaches developed for the nuclear power plants.
Within others, a Monte Carlo based approach has been proposed in Borgonovo, Marseguerra and Zio (2000), to model plant availability with maintenance, aging and obsolescence; the models for probabilistic safety assessment of aging equipment proposed by Cepin and Bris (2006), that discussed also about the strong uncertainties related to the ageing assessment (Kancev et al., 2011).

The severity of the consequences, that for major risk plants are usually worst case scenarios, apparently is not affected from ageing problems.

With respect to the decision making phase, ageing mitigation strategies can be implemented.

As an example, corrosion and erosion can be prevented or monitored and controlled.
Prevention methods include coatings and/or cathodic protection (often termed "CP"). CP can be achieved either by the use of impressed currents or by connection of sacrificial anodes typically made from zinc or aluminium blocks. If coatings are used there should be evidence of coatings inspection and if CP is employed evidence of maintenance and monitoring of CP effectiveness should be available.
For monitoring and control, management of corrosion is achieved through the following processes:

- Identification → usually involves a risk assessment, e.g. RBI plan or may take the form of asset registers arranged to identify those equipment items that are expected to corrode in one way or another.
- Detection → is the application of a suitable inspection technique, often visual, that can locate the corrosion
- Quantification → is achieved by measuring the remaining thickness of material available to contribute to the overall structural integrity of the equipment. In some instances, engineering judgement is applied but this should be documented to a sufficient extent that reasonable next inspection intervals can be deduced
- Assessment → whenever corrosion is detected an assessment should be made of its implications for equipment integrity. This assessment should inform any actions that are to be taken in the future including inspections and any repairs/modifications that may be made.

While good maintenance management processes and practices are central to ensuring that ageing safety-related E/C&I systems and equipment continue to operate reliably and with good availability. These issues are dealt with in detail in the referenced standards and guidelines, but in summary key aspects of maintenance management are as follows:

1. Maintenance Planning
2. Procurement - Spares and Support Issues
3. KPIs for Management of C&I Ageing – lagging and leading indicators
4. Plant History

In general terms the scheme of the relations within the safety management systems and the safety case – that contains the risk assessment – in terms of management of aging, can be borrowed by offshore process plants (Figure 3).

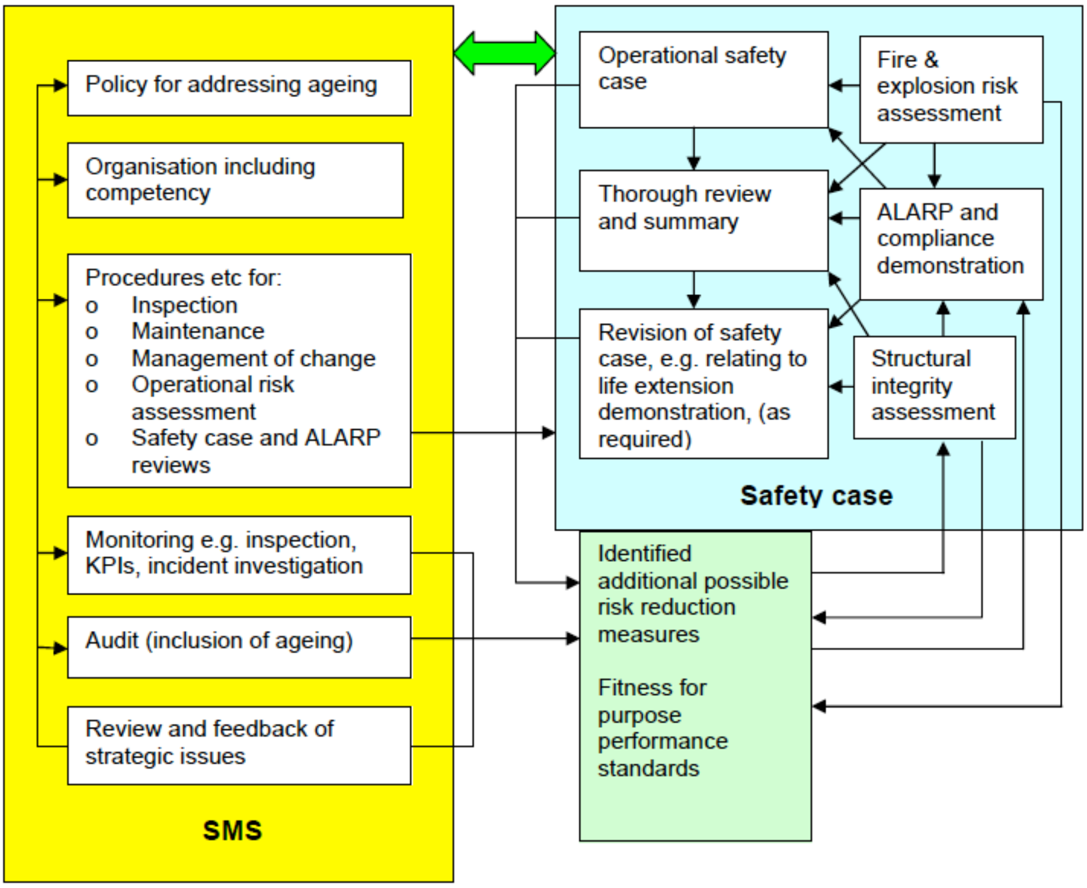

Figure 3. Relationships between SMS and safety case in terms of management of ageing

2.3 Operational control

It is recognized that maintenance is a central theme of plant management: an efficient maintenance policy may ensure safe, reliable and economic operation. On the contrary, an inefficient scheduling and choice of maintenance actions guarantees at least a waste of resources. In realistic situations, the maintenance activities become more and more frequent as the component ages. Thus the optimisation of maintenance - and a Maintenance Management Systems - should be an essential stage of operational control for ageing management.

The above system can be integrated in Asset Management and Integrity Systems to identify Critical plant and equipment, bringing to clearly identified and accessible

Asset Register documentation to ensure action is taken at the correct intervals, thus defining Audit and Inspection regimes.

One proposed approach is the Plant Lifetime Management (PLM) that is recognised to be an effective management tool to support the management of the ageing in process plant. The following steps have been proposed in Candreva and Houari (2013):

- Divide the plant into manageable systems or units and consider each system or unit
- Identify the critical equipment / components via a criticality screening process
- Evaluate the risks / failure scenarios for selected target assets
- Assess the remaining lifetime
- Identify mitigation measures for lifetime extension & establish Asset Life Plans

The steps above can be inflected as follows:

1. Data collection & condition assessment → Technical surveys & testing will be done as needed based on the scope definition and will allow identifying the most important degradation mechanisms and provides data related to the following topics: technical/mechanical integrity, operational integrity and design integrity.
2. Criticality screening → based on criticality ranking models, it aims at defining the most critical structures, systems and equipment/ components prioritising financial investments to the most essential elements. The criticality rank number of a system or equipment is a function of the system's or equipment's impact on the business when the system or equipment fails, regardless of how often the failure occurs.
3. Risk Assessment & Ranking → if the criticality screening tool is consequence-based, the risk assessment & ranking method considers also the failure frequencies. The classical risk assessment techniques can be used for risk assessment & risk ranking, provided that an appropriate risk matrix is used.
4. Remaining lifetime of critical assets → The Remaining Lifetime of critical assets with a high risk ranking can be estimated based upon considerations, as described in literature (IAEA, 2004 and HSE, 2006).
5. Mitigation measures for plant lifetime extension → Once the remaining lifetime is known the key issue is to decide how to intervene. The available options range from decommissioning to damage removal (with or without replacement), temporary repairs, undertake fitness-for-service assessment, changing operating practices etc. .

2.5 Key performance indicators

In recognising ageing mechanisms, key performance indicators (KPIs) can be identified and monitored to demonstrate how effectively the risks are being controlled. Both leading and lagging indicators must form a balanced approach to managing the risk control systems to ensure the risks are controlled to an acceptable level.

Lagging indicators measure outcome. An outcome is the desired safety condition that management arrangements should seek to deliver. Lagging indicators show when things have been going well or badly, e.g. by measuring incidents or accidents.

Leading indicators measure processes or inputs that are needed to deliver the desired safety outcome, e.g. by measuring whether MIT work has been completed to schedule.
An example sub-set of indicators for the EC&I systems is reported in (HSE, 2006):
Leading indicators

1. Number of defect reports per month for E/C&I equipment
2. Rising trends in failure rates for specific components or systems
3. Overrides: 'spot' values of the total number of overrides extant across the plant
4. Overrides: total number that have been newly applied during (say) the last month
5. Incidents arising from E/C&I failures
6. Safety or business-critical system downtime due to E/C&I failures

Leading indicators Examples:

1. E/C&I planned maintenance backlog
2. E/C&I reactive maintenance backlog
3. Maintenance support – remaining duration of existing contractual support
4. Spares holding for critical components
5. Management of Change (MoC): numbers of E/C&I MoC proposals in preparation or pending approval
6. MoC: numbers of E/C&I MoC proposals pending implementation
7. MoC: numbers of MoC proposals awaiting close-out of commissioning test reservations

4. Conclusion

It can be concluded that due to shortcomings in the regulatory framework until now in process industry, the effectiveness of companies managing the integrity of ageing assets was highly dependent on own initiatives and their application of industry best practices.
From the Seveso III on, the ageing of assets will have to be taken explicitly into account in the safety management systems of major risk plants.
Some key points has been discussed that should be addressed in ageing management of process plants.

References

Borgonovo E., Marseguerra M., Zio E. (2000) A Monte Carlo methodological approach to plant availability modeling with maintenance, aging and obsolescence Reliability Engineering and System Safety, 67, 61–73

Candreva F. and Houari M. (2013) Plant screening for ageing impact in the process industry, Chemical Engineering Transactions, 31, 253-258

Cepin M. and Bris R., (2006) Models of aging equipment in the probabilistic safety assessment Proceedings of the 31st ESReDA Seminar, Smolenice Castle, Slovakia, November 7-8

HSE (2006) Plant Ageing - Management of equipment containing hazardous fluids or pressure, HSE Research, Report RR509.

IAEA (2004) Management of lifecycle and ageing at nuclear power plants, TECDOC-1402,Vienna, Austria.
INERIS (2009) Benchmark international sur les réglementations et pratiques de maîtrise du vieillissement des installations industrielles, Rapport d'Étude réf DRA-09-102957-07985C, Paris, France.
Kancev D., Zerovnik G., Cepin M. (2011) Uncertainty analysis in the nuclear industry: Analytical unavailability modelling incorporating ageing of safety components Journal of Loss Prevention in the Process Industries, 24, 397-404
EC, (2012) Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC, 2012