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Ageing and Creeping Management in Major Accident Plants according to Seveso III Directive

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The focus of this paper is the management of critical equipment ageing within the context of lower and upper tier Seveso process plants, with a peculiar insight into the effectiveness of safety management systems in setting-up reliable procedure for critical element identification. Recent research studies in fact evidenced that in Europe nearly 50% of major ‘loss of containment’ events, arising from technical plant failures, were primarily due to ageing plant mechanisms such as erosion, corrosion and fatigue. The critical ageing elements should be included in maintenance, inspection and periodic monitoring programs in relation to their reliability, as assumed in the risk assessment and their lifetime or frequency ranges, based on their operational experience. This paper will accurately discuss how the issue of ageing is currently handled in the process industry. The methodology builds on the critical results of actual findings from the inspections on the safety management systems of major accident plants, which were performed by a working group. The primary objective is to stimulate the introduction of effective ageing management changes into the safety management of companies, by taking advantages of findings of the previous assessment and establishing proper and effective audits.

1. Introduction

The safety performance of a Seveso establishment is connected to three elements, namely the technical integrity of its installations, the HSE management system and the company safety culture. The first requirement to achieve a good safety performance is that the technical installations are properly designed, regularly inspected and well maintained as the time goes on. It is noteworthy noting that in several European countries the industrial base assets is ageing with an estimated 50% of plants continuing to be used beyond its originally planned operational life spam. The economic crises may pose additional hazards leading to some changes, due to the combination of the general degradation of plant and equipment due to ageing with changes in the plant ownership and management procedures. Wintle, (2006) provided a useful definition on the issue of ageing, primarily focusing on process plants: “Ageing is not about how old your equipment is; 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 with an increasing likelihood of failure over the lifetime. The significance of deterioration and damage relates to the potential effect on the equipment’s functionality, availability, reliability and safety”. According to the definition, an aged plant is, or may be, no longer considered fully fit for its purpose due to deterioration or obsolescence in its integrity or functional performance, without a univocal relationship with the chronological age. There are several examples of very old plant, remaining fully fit for purpose, and of recent plant, showing evidence of accelerated or early ageing, e.g. due to corrosion, fatigue or erosion. A recent survey of accidents in the downstream oil sector, collecting a sample of 1050 events (Fabiano and Currò, 2012), evidenced that the highest percentage (64.8%) corresponds to the headline plant/process, with main direct causes related to “failure/damage to reactors, vessels, equipment”, “component failure/malfunction” and “piping loss of containment”. The observation highlights how the issues of lifetime extension and related ageing implications, in terms of potential loss of containment, are to be considered of primary importance in relation with process/storage vessels and piping,

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where in case of accident the dominant scenario is pool fire (Palazzi et al., 2017). Similar issues, even if not identical, are posed by creeping changes, i.e. the accumulation of gradual, unplanned small changes, which may cause failures with consequences for assets, people, environment and loss of production. Ageing and creeping can be recognized as contributing factors in striking high profile accidents, e.g. Bhopal (Palazzi et al., 2015) and Texas City (Kalantarnia et al., 2010). Additionally, the issue of ageing, due to the increased potential of loss of containment and other failures, has been shown to be a relevant factor in several European accidents. Horrocks et al. (2010) starting from the EU Major Accident Database (MARS) argued that, over the time span 1980-2006, there have been 96 major accidents potential loss of containment incidents which are estimated to be primarily caused by ageing. This figure represents 30% of all reported 'major accident' in the MARS database and 50% of the technical integrity and control and instrumentation related events. The severity of these events was evaluated in overall loss of 11 lives, 183 injuries and over 170 M€ of economic losses, thus providing empirical evidence of the significant extent and impact of ageing plant related failures on both safety and economic performance. The remainder of the paper includes a discussion on the issues of ageing and creeping within the Seveso establishments; the outline of a framework for ageing management evaluation and the results of some Seveso inspections including relevant criticalities evidenced with respect to the ageing management.

2. Ageing and creeping within Seveso establishments

A crucial requirement of the EC Seveso Directive is the provision of a Safety Management System (SMS) for companies falling under this legislation, thus allowing supervision of items to be covered by the mandatory Seveso inspections. The critical items should be included in maintenance, inspection and periodic monitoring programs in relation to their reliability, as assumed in the risk assessment and their lifetime or frequency ranges, and based on their operational experience. Plant ageing should be managed as part of a well-structured SMS. In several instances, the term "ageing" may not be mentioned explicitly but its management should be catered for in the management of systems' integrity and functionality that covers all asset types. A well-structured and maintained SMS document is a means of identifying and setting down a commitment to how a company will manage health, safety and environmental issues. Larger companies have to develop such a document and refer to several standards, procedures and methods by which they will maintain performance across all sections of their business. Many small and middle-sized companies also have the required standards and documented procedures, but they may not have these requirements organized into a document explaining how these will be implemented and guaranteed. The identification and management of ageing issues in relation to the process safety is recognized in a number of key risk control systems, which must be correctly identified and fully documented, so that they are regularly audited, reviewed and updated. Key elements include:

- Maintenance Management Systems
- Asset Management and Integrity Systems
- Audit and Inspection regimes
- Risk Assessment Management processes
- Management of Change procedures
- Permit to Work
- Responsibilities and Communications
- Training and Competence development

It is important to recognize that many systems and features that may be subject to ageing can contribute to HSE performances of a process plant, which can be compromised in case of failing or collapse. A holistic view is therefore required when assessing the potential impact of ageing at a given installation. Systems can be grouped in the following main categories, namely: primary containment systems; control & mitigation measures (safeguards); EC&I systems; physical structures.

EC&I systems can be considered as a type of safeguard. However, given the different nature and relative importance of the functions performed by this type of equipment, it is considered desirable to highlight this category specifically. Seveso Directive III underlines that a Safety Management System should be created for the identification of hazards and the assessment of relevant risks, deriving from normal or abnormal activities, in order to ensure the correct application of key risk control systems and the maintenance over time taking into account of cost and benefits (Abrahamens et al. 2018). In particular, referring to operational control, the main requirements include:

- Verifying that the criteria adopted to identify the critical elements of plant has taken into account the hazard assessment and the structure of plant.
- Verifying that the manager has systematically identified critical elements, based on the chosen criteria.

- Verifying that critical elements are included in the periodic maintenance, inspection and control programs, in relation to their reliability, as assumed in the risk assessment (i.e. their lifetime or fault frequencies specified by the supplier or established by the operative experience analysis and previous check results).
- Verifying that a monitoring and control plans of ageing risks (corrosion, erosion, fatigue, viscous sliding) of equipment, that may lead to loss of containment of dangerous substances, including the necessary corrective and preventive measures, has been foreseen.

In the safety of complex systems, the key concepts are identified as follows:

- Reliability: the ability to achieve the desired goal without errors
- Availability: the ability to fulfill the mission assigned at that specific time of the system's lifetime

As amply known, these represent important parameters to estimate system performances, compared to its ability to achieve the mission required in a given period. Various generic ageing mechanisms can be present in an industrial plant, depending on the actual circumstances, and affect a variety of asset types. A summary of degradation mechanisms and potential affected assets are summarized in Table 1.

Table 1: Ageing mechanisms affecting physical assets.

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

Ageing would be expected to be more prevalent where there is some degree of incompatibility between the process fluids and the materials of construction of the equipment. Table 1 provides an indicative guide to identify which equipment may be more likely affected by degradation, starting from P&I critical review and material compatibility data. The integrity plan of critical systems and components for the Major Accidents Prevention must ensure both the containment of hazardous substances in the critical equipment and/or lines, and the operating of active and passive safety systems. These last ones generally consist of:

- Systems for the pressure discharge and conveyance of vents;
- Emergency systems, such as flares, blow-down systems, etc.;
- Equipment and plant interception systems;
- Alarms and automatic locks;
- Fire detection and fire protection systems (e.g. cooling water, etc.);
- Detection systems for hazardous liquids and gases (toxic and / or flammable);
- Emergency services and related mobile equipment.

If the operational control in the production, transfer, storage and distribution of hazardous substances, can give rise to major accidents (due to accidental release and/or process anomalies), it must be implemented according to specific procedures and/or operating instructions. The identification of critical equipment and lines must be included in the risk analysis or in the plant safety report (RDS). It must form the basis for defining a specific inspection/control plan. Preventive, scheduled maintenance or failure of critical equipment or lines can be performed according to the available criteria or Best Practices of RBM (Risk Based Maintenance). These maintenance operations should minimize the risk of loss of containment and ensure the functionality of critical equipment (e.g. pumps, compressors and exchangers) for the major accidents prevention.

3. A framework for ageing management evaluation

The correct management of risks due to ageing in process plants can be faced by adopting Risk-Based Inspection standards (ASME, API or RIMAP), based on the use of subjective compensatory factors (Bragatto and Milazzo, 2016) that introduces uncertainties in the assessment (Milazzo and Aven, 2012). In the following, the development of a preliminary framework, aimed at identifying the key factors that have an inevitable accelerating effect on ageing and those having a slowing-down effect, is outlined. Such approach is conceptually based on a fishbone analysis (Figure 1) and it application relies on a number of assumptions and methods amply applied in the process sector (Reason, 1997):

- The nature of socio-technical systems in a dynamic and time-changing operational and physical environment implies that lacks in the protective layers are inevitable;
- Ageing related accidents and near-misses generally take place when human and organizational factors align to cause lacks in the technical and operational preventive layers;
- Ageing accident probability can be reduced if the firm:
  - identifies in a proactive way ageing hazards and design/operational mitigating protection layers;
  - performs a continuous effort to identify and address latent conditions (including those related to operational and organizational factors);
  - set-up proper safeguards and manages the consequences of active failures related to ageing (technical and human factors).

Analogously to other index methods, both accelerating and the slowing factors translate respectively into penalties and credits, then, the overall evaluation of the system is given by the whole critical analysis.
As a first attempt for the scoring system, a single numerical value is assigned to penalty and credit factors. An Ageing Compensation Index (ACI) ≤ 0 implies that ageing risk is correctly managed, within the considered setting, and adequate to guarantee that it is operating within safety margins. On the contrary, if ACI>0, actions should be properly implemented to correctly face ageing phenomena, especially when possible lifetime extension has to be evaluated. This last issue and its implications, in terms of potential loss of containment, are of primary importance in relation with process/storage vessels and piping where ageing deterioration can have a multifaceted nature, notwithstanding the enforcement of inspection methods, e.g. API 572 (Vairo et al., 2017).

4. Seveso establishment inspections

The third improved version of the EU Directive on the prevention of major accidents involving dangerous substances, inspired by the well-known Seveso incident, has entered into force on the 1st June 2015. Its main evolution is connected to the enforcement of the legislation concerning the Classification, Labelling and Packaging of chemical substances and mixtures (CLP) (Fabiano et al., 2016). Additionally, Seveso III Directive foresees an evaluation approach and relevant safety issues and procedure for planning routine and non-routine inspections of establishments falling under its competence. In the following, the results of routine inspections, carried out for 15 Seveso establishments located in the Northern part of Italy (Liguria), are outlined with the main focus of evaluating the soundness of the firms' SMS, the appropriateness of the safety management activities and the overall effectiveness of safety-related activities. The inspections on the SMSs were carried out for 9 upper and 6 lower tier Seveso establishments, covering the process sectors and shown in Figure 2. The main purpose of the site inspections in the selected establishments at major accident risk was the actual verification of relevant elements of the management. system policy of the company and the overall safety culture as detailed in the following.

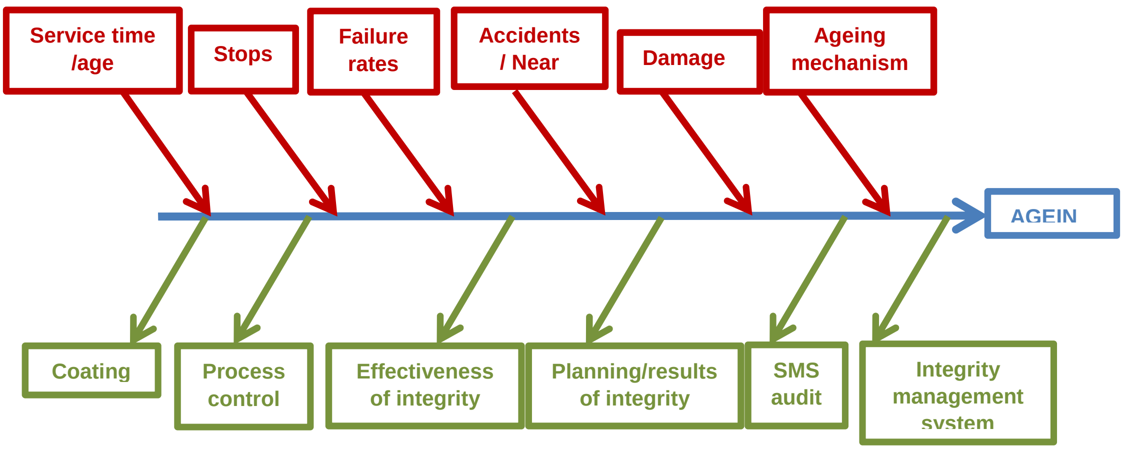


Figure 1: Ageing fishbone diagram (upper, red: enhancing factors; lower, green: mitigating factors).

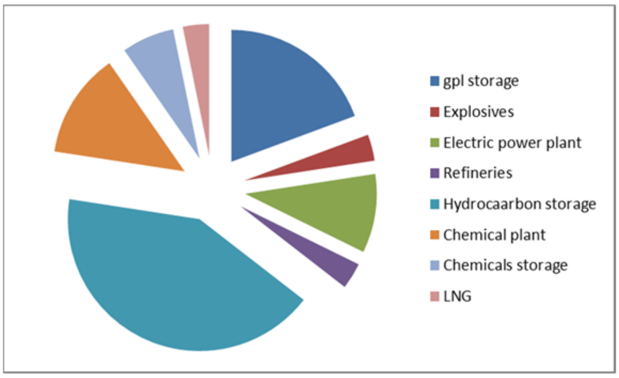


Figure 2: Distribution of Seveso installations under investigation in the Northern Italy.

- Implementation of the major accident prevention policy declared by the operator, by analyzing the results actually achieved on the basis of the stated objectives and principles;
- Compliance of the SMS with both the structural requirements and the contents required by the regulations;
- Functionality of the SMS, the implementation modalities, the understanding and the degree of involvement of the persons who are called to carry out safety-relevant functions or actions, at every level of the system;
- Presence of risks for the environment and populations connected to the plant's location, the proximity of other plants at major accident risk and the handling of dangerous substances.

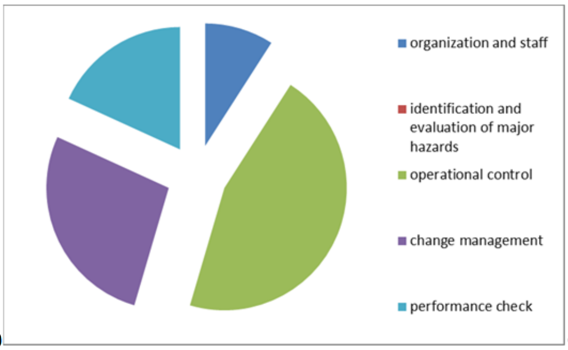
The main elements of a SMS that were critically and thoroughly analyzed can be summarized as follows:

1. Prevention policy document, SMS structure and its integration with company management
2. Organization and staff
3. Major Hazard identification and evaluation
4. Operational control
5. Management of change
6. Emergency planning
7. Performance check
8. Check and revisions

A statistical overview of the minor and major non-compliances, verified during the Seveso site inspections, is respectively provided in Figure 3a and 3b. The most relevant critical points of the safety management systems turned out to be connected items 4 and 7:

- Operational control: critical elements identification; maintenance processes management; ageing management.
- Performance check: operational experience analysis.

Starting from the premises that all the processes must be based on a "robust" risk assessment, relevant examples of non-compliance related to the ageing management resulting from inspections may include the items summarized in the following.

(a)


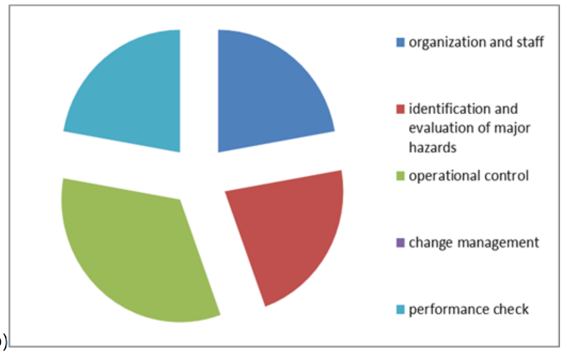
(b)


Figure 3: Main findings from Seveso sites inspections: a) minor non-compliances; b) major non-compliances.

- Concerning the identification of plants and equipment subject to verification plans, the criteria for identifying critical equipment are missing;
- The analysis of operational experience is poor;
- The management should investigate the problems related to ageing (corrosion, erosion, fatigue and creep) of equipment and plants, which can lead to HazMat loss of containment, by providing, where appropriate, a specific monitoring and control plan, including corrective and preventive measures;
- Absence of formal and/or practical evidences of a plan to effectively monitor and control the risks associated with the ageing of equipment (except legal obligations).

5. Conclusions

The SMS should ensure that each critical equipment is subjected to a schedule of checks (maintenance and verification) adequately planned in order to guarantee over the lifetime the attainment of safety requirements. To ensure sufficient mechanical integrity of the components related to the operational processes, a systematization of the methodologies for the equipment control is advisable. The findings of the inspections and the developed framework suggest that in case of unsatisfactory ageing assessment, the correct management of this issue within the given process plant should consider possible improvements in terms of:

- Scheduled update of procedures to improve maintenance, testing and audits, covering also structural requirements;
- Investigation on ageing characteristics (e.g. relevant corrosion behavior) resulting from process changes, or environment alteration (land-use modifications);
- Accountability of creeping and ageing management, by selecting and training managers and workforce;
- Strategic decision for lifetime extension performed on the basis of a hazard based ageing approach, including critical review of all periodic inspection reports, with significant trend indicator.

As quoted by Vaughen and Klein (2011), Trevor Kletz gave a monitus about senior managers that have taken their eye off from the right direction, thus allowing the safety culture to decay from both top-down and bottom-up. His amply-known motto is well relevant to the ageing issue within the broad context of process plants: “if we don’t have it, it can’t leak”; but if we have it, we must manage its ageing, otherwise it will leak.

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