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# AGEING OF HAZARDOUS INSTALLATIONS

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**No. 29**

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Series on Chemical Accidents

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# AGEING OF HAZARDOUS INSTALLATIONS

IOMC

INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

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**Paris 2017**

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# FOREWORD

This paper brings together information collected through discussions and projects undertaken by the OECD Working Group on Chemical Accidents (WGCA) relevant to ageing of hazardous installations over the 2014 to 2016 period. It relies, in particular, on the results of an analysis of accidents associated with ageing of installations, on the results of a survey activity that aimed to collect information on the approaches of countries to ageing of installations, and on the conclusions of a Special Session that was organised in October 2015 by the WGCA on Ageing of Hazardous Installations.

The analysis of accidents associated with ageing of installations was prepared by the Major Accident Hazards Bureau of the European Commission Joint Research Centre. The following delegations provided cases of accidents associated with ageing: Australia, France, Germany, Italy, Sweden, the Netherlands, and the United Kingdom.

Regarding the survey activity, a questionnaire was prepared and sent to WGCA member delegations in 2014. The following delegations provided responses to the questionnaire: Australia, Belgium, Estonia, Finland, Germany, Italy, The Netherlands, New Zealand, Norway, Slovakia, Sweden, Switzerland, and the United Kingdom.

An OECD Special Session on Ageing of Hazardous Installations was organised on the 28$^{th}$ of October 2015 in the framework of the 25$^{th}$ WGCA meeting.

The project on ageing of hazardous installations was managed by a steering group composed of the following countries: France, Czech Republic, Germany, Iceland, the Netherlands, Norway, the United Kingdom, and the European Union.

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## EXECUTIVE SUMMARY

1. Ageing of hazardous installations has been the subject of increasing attention in the past decade, both by public authorities and industry. Indeed, worldwide, and in particular across OECD countries, many of the currently operating chemical facilities[1] have reached or exceeded the end of their nominal design life which is typically set at 20 to 25 years. Many of these facilities were built in the post Second World War period and in 2016 facilities can now be up to 75 years old and still in service. This raises questions as to how best to manage these older facilities, and how to anticipate ageing in newer ones.

2. In 2013, the OECD Working Group on Chemical Accidents initiated a project on Ageing of Hazardous Installations, the objective of which was to get a better understanding of what ageing is and its implications. The project sought to identify the risk factors associated with ageing facilities, establish whether ageing is a cause of accidents, and discover how ageing is being approached by public authorities and whether ageing is addressed as a specific subject in policy and regulations. The results of the activities conducted within the framework of this project are presented in this report.

3. One of the main conclusions from the report is that ageing is a multi-aspect phenomenon. One of the best known aspects of ageing is the physical ageing of equipment, not necessarily linked to chronological ageing *per se* but to the degradation of equipment over time from its initial condition, however this is just one aspect of ageing facilities and only one of the associated risk factors. Everything associated with a site and its processes can age, not only equipment but people, procedures and technologies. It can therefore be expected that older facilities, in particular the oldest, present particular issues compared to more modern facilities that require particular attention.

4. From the day of their construction, older facilities will see significant developments and changes in engineering, policy and regulations, and in the overall socio-economic conditions under which they operate. For example the introduction of legislative frameworks for hazardous facilities in the past decades, the development of new safety standards and new operating procedures following new discoveries in science and engineering have led to a need for an upgrade in many of these facilities. This can be both a technical and financial challenge.

5. Additionally the landscape of the chemical industry has evolved significantly since the 1950s with major changes in the structure and ownership of companies. Older facilities are likely to have been modified a number of times and to potentially have changed owners on several occasions. Another phenomenon that emerges strongly from the OECD project is the significant growth in the contracting out of key operations in chemical facilities, for example engineering and maintenance. These developments raise particular concerns such as:

- The potential loss of knowledge and expertise, in particular regarding the history of the facility; and

- The way third parties engaged to work at the facility are recruited and supervised, and what information they are provided with.

[1] Including facilities storing or processing other hazardous substances especially mineral oil or mineral oil products.

6. These concerns were highlighted as specific risk factors in the analysis of accidents associated with ageing that was conducted in the framework of the project. Most of the accidents analysed in this report were associated with degradation mechanisms (principally corrosion), resulting from a defect in the way ageing had been addressed in the Safety Management System of the facility. The risk factors emphasised by the analysis are:

- ***The engagement of third party personnel to work at the facility*** with insufficient knowledge of the facility's history, insufficient information concerning equipment most likely to be affected by ageing, and / or inadequate supervision and monitoring;

- ***Missing or incomplete documentation on the design, operation and history of the facility*** including information on the replacement of equipment, any new equipment, past defects and information on the frequency and type of use of particular pieces of equipment, particularly those likely to be affected by ageing;

- Availability of information: this may be hampered by the transition from paper to electronic systems or other changes;

- ***Loss of knowledge about the design and operation of the plant:*** depending on the age of a specific facility, it is likely that many or all of the original design and operating team will have moved on or retired. Unless this knowledge and experience has been captured they will have taken with them unwritten history, knowledge of previous incidents valuable to continuing operation;

- ***Inspection plans*** that do not sufficiently provide for the monitoring of critical pieces of equipment particularly subject to ageing; and

- ***The absence of risk assessments,*** before changing the way in which a piece of equipment is to be used. This can, for example, lead to a higher mechanical stress on a piece of equipment, not being taken into consideration and ultimately leading to failure.

7. In summary, the safe operation of an older facility is dependent on the capability of the operator to understand its operation and integrate the different aspects of ageing into monitoring and maintenance plans. It also depends on the corporate management strategy of the organisation which owns the facility. Facilities can "age" more rapidly if not managed properly, and two facilities of similar age could be in very different condition depending on how they have been maintained.

8. A significant factor in an inconsistent approach to dealing with ageing at hazardous facilities has been the lack of a common definition of ageing, although recently a tacit understanding of what the term could imply for chemical facilities has begun to develop. A lack of definition has contributed to the position that, until relatively recently, ageing was not generally considered as a separate subject requiring particular attention but rather generally addressed and covered under the 'normal" degradation monitoring of the plant. Some countries have included the management of ageing in legal obligations to operate installations according to best available techniques or state of the art (for example, the German Major Accident Ordinance), and the Seveso III Directive now specifically requires the operators of establishments to address ageing issues in their Safety Management System. Also countries, such as France and the United Kingdom, have developed specific plans for addressing ageing of facilities, challenging companies in the way they are monitoring ageing of equipment.

9. Overall this report highlights the importance of addressing all aspects of ageing at facilities as a specific subject. To facilitate this, a reasonable and practical definition of ageing as well as a more

thorough understanding of the factors influencing ageing of installations would be very important to develop. There is also a great opportunity for awareness raising and involvement of senior leaders on the risks that can be associated with ageing facilities.

## INTRODUCTION TO AGEING OF HAZARDOUS INSTALLATIONS

10. This section presents the main conclusions from discussions within the OECD Working Group on Chemical Accidents on the meaning of ageing within the field of chemical process safety and the different elements that could age in hazardous installations. It relies, in particular, on the conclusions of a Special Session that was organised in October 2015 by the OECD Working Group on Ageing of Hazardous Installations.

### What is meant by ageing of installations?

11. Worldwide, and in particular across OECD countries, many of the currently operating chemical facilities have reached or even exceeded the end of their nominal design life, typically set at about 20 to 25 years (a range limit based on current industry experience as well as investment appraisal purposes)[2] with a significant number having been constructed during the post Second World War period. In 2016, some facilities can be up to 75 years old and still in service. This raises concern as to whether those facilities comply with current good practice for safety management and for preventing accidents and minimising their consequences.

#### *Ageing of equipment/material degradation*

12. When thinking about ageing facilities, the first element that comes to mind is the ageing of equipment. Most equipment will start to degrade on entry into service and over time this degradation can lead to failure. Corrosion is the most well-known ageing phenomenon and is still a frequent cause of accidents (see next chapter on accidents associated with ageing). It is important to highlight that ageing is not simply the chronological age of a piece of equipment but is related to what is known about the condition of a piece of equipment and how this changes over time. The United Kingdom defines this as "the degradation of equipment from its new condition"[3]. The evolution of a facility over time will very much depend on how it has been maintained and on the safety management system under which it operates, as well as other factors including environmental and specific operating conditions. These factors mean it is likely for two facilities built in the same year to be in a very different condition ten or twenty years later.

[2] Including plants storing or processing other hazardous substances especially mineral oil or mineral oil products.

[3] The definition used derives from HSE Research reported in Research Report 509, see http://www.hse.gov.uk/research/rrhtm/rr509.htm Research Report RR509

**Box 1. How is ageing defined across countries?**

According to a survey that was conducted within the framework of the WGCA project on ageing of hazardous installations, it appears that there is not a clear definition of ageing that is used across countries[4]. In fact very few countries have a definition of ageing and it is often not considered as a separate subject requiring specific attention and as such is not directly mentioned in regulations and policy. There is however a tacit understanding of what ageing means, most frequently associated with degradation mechanisms and inadequate maintenance and is covered as such in policy and regulations. This tendency might change now, for example in the EU, with the implementation in 2015 of the Seveso III Directive that requires operators of establishments to address ageing issues in their Safety Management System, as specified in Annex III of Seveso III. There seems to be a common understanding developing that ageing is not necessarily associated with the age of a plant per se, but to the degradation mechanisms that will cause a particular piece of equipment to deteriorate from its initial condition or from the condition observed at a particular point in time.

### *Ageing of people, procedures and technologies*

13. Activities conducted within the framework of the WGCA project, showed that ageing of equipment is just one aspect of the change in risk over the lifetime of the facility. Everything associated with a site and its processes can age, not only equipment but people, procedures and technologies. These factors are usually defined as obsolescence, and organisational ageing (see Figure 1). It can therefore be expected that, older facilities, in particular the oldest ones, will present some specific issues compared to more modern facilities requiring particular attention. The technology and equipment used by the facility may be obsolete and may have been changed/modified a number of times over the years. Knowledge and documentation on the operation of a facility may also have been lost with the years as paper records move online and personnel move on or retire.

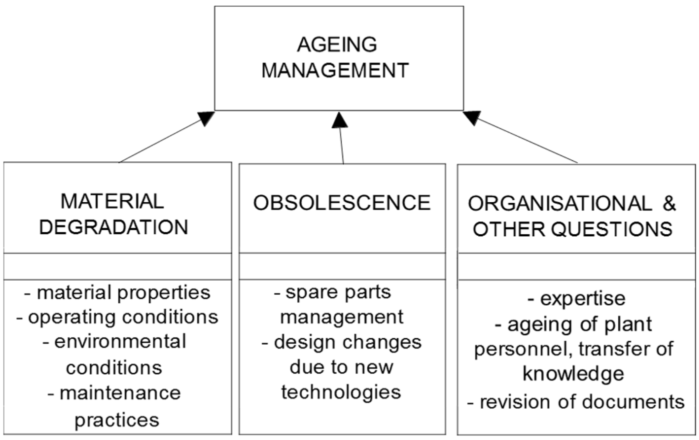



**Figure 1. Categories of ageing (Source: ESReDa, Ageing of Components and Systems, Eds.: Lars Petterson and Kaisa Simola. An ESReDA Working Group Report. Det Norske Veritas, 2006)**

14. When considering ageing it is important to not only consider individual components but also to the systems within which they function. Some of the more significant systems that can age are:

4 A questionnaire was prepared and sent to WGCA member delegations in 2014 to gather information on the way countries were approaching ageing plants. One of the questions in the questionnaire was: "How is the term "ageing", when related to hazardous installations, defined in your country?". Nineteen responses were received to this question from different government agencies in the following countries: Australia, Belgium, Estonia, Finland, Germany, Italy, The Netherlands, New Zealand, Norway, Slovakia, Sweden, Switzerland, and the United Kingdom.

*People*

15. Demographic and structural changes in society mean that the average age of the working population in many industrialised countries is rising meaning that the effects of an ageing population need to be reflected in operational process safety. Whilst a potentially ageing workforce can have significant benefits such as the retention of experience and knowledge there may be other impacts which need to be considered. These are changes in human performance which are generally true throughout the population such as:

- Increased reaction times;
- Deterioration of eyesight and hearing; and
- Decrease in agility and potential ability to work at heights or in more exposed locations.

16. The consequences of these natural processes need to be taken into consideration when reviewing processes and procedures or when carrying out modifications, for example in maintenance and inspection activities which may involve climbing or working in cramped positions or not easily accessible locations. Taking this into account, consideration should be given to the appropriate tasks for older workers; those should be adapted to their physical capabilities as age increases and might be orientated, for example, toward knowledge transfer to younger workers, as well as supervision activities.

*Procedures*

17. Procedures should be regularly reviewed and kept up to date, ensuring that changes in equipment, process parameters or legal requirements are reflected. Procedures should also be reviewed to ensure that experience gained and developments in best practice are incorporated. Any change to procedures should lead to a review, and where necessary update, of systems for monitoring and distribution of those procedures. This will ensure that old information is replaced with old and that out of date procedures do not remain in circulation potentially leading to incorrect or dangerous operating conditions.

*Electrical and Electronic Systems*

18. Electrical and electronic systems encompass the entire spectrum from the power supply through to micro-electronics found in IT and control systems. Particular ageing issues concerning these systems which should be considered are;

- ***Loading*** **-** the amount of power required by a facility will often have increased significantly over time requiring a reassessment of power distribution networks, transformers and emergency power supply systems. Such a reassessment should particularly address restarting of large equipment following a power outage may lead to such a demand on the power supply that the network may become instable and collapse or initiate load-shedding.
- ***Buried cables*** – are liable to suffer damage over time, for example due to third party damage such as construction or due to earth movements or influences from nature such as vegetation growth or rodent attack. Damage to buried cable may lead to the ingress of water, short circuit and subsequent power failure[5].

[5] Third party damage can also cause important instantaneous effects that will affect the facility.

- ***Wear*** – over time components such as electro-mechanical switching, springs or mechanical retention systems may develop signs of wear leading to failure.

19. Electrical and electronic systems are also vulnerable to the effects of obsolescence with new generations of components not being generally compatible with those of the previous generation. Failure to be aware of such developments and take timely action can mean, not only unplanned costs and interruption of operations, but that but also that components may fail and require replacing when spare parts are no longer available.

*Software and Control Systems*

20. Software and control systems are particularly vulnerable to obsolescence due to the rapid change in technological development. Obsolescence of these systems affects not only the operation of the facility and the visual display systems, but also the recording, analysis and archiving of data. Maintaining software systems, readability and compatibility of data and file types is a major investment. This covers many different activities from the documentation of the hazard identification and risk assessment process, through to plans and drawings. The consequences of software upgrades in control systems, computer operating systems and individual software applications need to be assessed within the management of change process in order to avoid obsolescence, and also the effects of unintended changes. This is particularly critical when safety relevant information is altered in its presentation or function (for example, alarms and alarm management).

*Non-metallic systems*

21. In many modern chemical processes non-metallic materials such as polymers (plastics and duroplasts), and glass as well as composites are used. Whilst these materials may not corrode in the way that metals do, they may be sensitive to ageing in other ways such as UV-radiation leading to, amongst other things, embrittlement, stress loading, leaching of stabilizers, plasticizers, fillers. The experience with these materials is relatively short when compared with metallic materials. Therefore operators, inspection bodies and authorities need to be particularly aware of the potential for change in performance over time.

**Scientific, economic and societal changes of the past decades that have had an impact on older facilities**

22. Older facilities will have been exposed to significant scientific, economic and societal developments leading to changes in the overall conditions and frameworks under which they have been operating and ageing. The period of 1960s-80s saw significant advances in technical and engineering knowledge concerning risk management including the development of codes of practice, new engineering practices (for example due to the development of computers), risk analyses, process control technology and safety performance standards. During this period academia, industry and public authorities devoted significant engineering resource to developing more effective codes and sharing best practices. The development of process safety has also led to better design approaches to prevent releases. Past accidents have led to changes in procedures and the development of more structured approaches to accident prevention. These developments can be designed into new facilities at construction stage allowing for better integrity management, process controls and layouts to minimise ignition, explosion overpressures and fire escalation, in principle, leading to improvements in understanding and managing ageing and its consequences.

23. With these developments, older facilities may need to upscale to current standards of safety and develop new operating procedures. However it will often be impractical to change some aspects of the design, such as the core processing and the layout, meaning that the risk levels can never be reduced to

those of a more modern facility. This can be both a technical and financial challenge. An older facility may have lots of defects and require significant resources to be brought up to new norms; in particular if shut downs are necessary for repairs and upgrades to be completed. The economic situation in the past decades has put even greater pressure on uneconomic facilities, which may already be at higher risk of experiencing degradation through ageing leading to failure. Companies may take a strategic look at their hazardous facilities and chose to divest themselves of those which are high risk, high cost, and low profit. These facilities may be passed on to other operators with less experience, resources and inferior safety management systems.

24. In general, business has evolved in recent years with privatisation and major changes in the structure and ownership of companies. There has also been a major growth in the contracting out of engineering, maintenance and operation in chemical facilities. The workforce, including those who build and operated the facilities, has been ageing or retiring. These factors can potentially lead to a loss of knowledge and experience on the operation of the facilities.

25. The period since the Second World War has also seen the development of major hazard legislation across countries, for example the introduction of the Seveso Directive in 1982 required both operators and regulators to take a structured approach to risk analysis and management introducing concepts of identifying hazards and carrying out risk assessments to identify appropriate mitigation measures. The Seveso III Directive, implemented in 2015, now specifically mentions ageing in its Annex III. Specific programmes and guidance documents relating to ageing management have been developed over the years also by several research centres and industry groups.

26. The development of computing technologies has transformed the way knowledge of a facility is managed. Forty years ago drawings of equipment and installations were hand-made and manuals for process safety management were individually typed and photocopied. These documents are likely to have now been converted to an electronic format. This can be seen as a great improvement to facilitate knowledge sharing however there is a risk that information can be lost during the transition. Computer technology has also changed the way facilities are designed and operated, where previously calculations for the lay-out were made with a slide rule and process control was made by personnel, the design of processes and lay-out of equipment is now made by methods requiring computers (for example, finite element calculation) and facilities are controlled by computer systems.

27. Linked to the above point, one of the main concerns for an older facility is the potential loss of knowledge and expertise that has occurred over time. Lessons learned have been lost as key personnel have retired or moved on. This ageing phenomenon is the most challenging to monitor and address because it is about trying to compensate for something that may no longer exist or may no longer be accessible, both in terms of people and documentation. It can be seen that risk increases where there is missing or poor quality documentation linked to older processes and equipment, which may have been associated with important risk scenarios. There are also the “unknown unknowns”, for example documentation could be missing about a change made in previous years but there are no personnel present at the time in the facility to highlight that the information is no longer available.

**Older facilities in summary**

28. Taking a decision on whether and how to operate an older installation can be complex and depend on a number of factors:

- Whether the design of older facilities is inherently less safe than more modern ones;
- Who the facility is owned and operated by;

- What condition the facility is in;
- Whether the facility is less economic than a more modern facility;
- Whether the facility can be brought up to the latest standards, and at what cost;
- Whether the facility can be run to tolerable risk levels, if not brought up to the latest standards.

29. Older facilities present different risks than more modern facilities. They are not necessarily more unsafe from an integrity perspective but they present some specific issues which need to be considered for example, factors of safety in older design codes were often greater than their more modern counterparts, as uncertainties and a lack of understanding often led to over-engineering. However, advances in materials and welding have led to improvement in construction standards. Older facilities may be less economic because of the needs for upgrade, and because they may be more costly to operate and maintain. The procedural controls to limit risk in older facilities may require better competences, supervision, and tighter operating limits requiring possibly greater interruption to production. Older facilities often were built to meet a demand from 30 to 50 years ago and may not be capable of meeting modern needs in term of efficiency of production.

30. In addition, older facilities are likely to have been modified a number of times, and to potentially have had several different owners and operators or been part of mergers and divestments. Change of ownership in these facilities can lead to a change in the management of the risks of the facility[6], and can one of the reasons for ageing problems in relation to record keeping. After a change of ownership there can be loss of records, and understanding of the process of the facility.

31. The appropriate operation of an older facility depends on the competencies of the operator and on the corporate management strategy of the owning organisation. The owners must take decisions on the condition of the facility and on its operation– for example, whether it should shut down, if operations should be limited, or if upgrades should be carried out. What the "tolerable risk" for running old facilities is a difficult judgement for both operators and regulators.

6 OECD (2016), Synthesis Report: Special Session on Facilities Handling Hazardous Substances with Ownership Change, No. 28, ENV/JM/MONO(2016)10, see http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2016)10&doclanguage=en

## ACCIDENTS AND AGEING OF INSTALLATIONS*

** This section was prepared by Dr. Zsuzsanna Gyenes of the Major Accident Bureau of the Joint Research Centre of the European Commission*

32. This section presents the main conclusions from an analysis of accidents associated with ageing conducted by the Major Accident Bureau of the Joint Research Centre of the European Commission. As part of this activity, delegations to the OECD Working Group on Chemical Accidents were invited to provide cases of accidents that had been identified as associated with the ageing of installations.

33. Cases of accidents were received from: Australia, France, Germany, Italy, Sweden, the Netherlands, and the United Kingdom. In total 430 accident reports were analysed with the aim of highlighting any commonalities across accidents as well as lessons learned.

### Method of selection of the accidents

34. All the cases of accidents were provided using a common reporting template, which is the one prepared by the Major Accident Hazards Bureau of the Joint Research Centre to complete this analysis. However there was a great diversity in the content and the quality of the reports, as such allowing only for a rather qualitative analysis with no statistical significance.

35. For the analysis, accidents have been regrouped based on their causes, technical or procedural (that is linked to the Safety Management System of the facility). Accidents meeting the following criteria were also excluded:

- occurred pre-2000;
- led to small amounts (few kilograms) of released chemicals; and
- involved substances that are not classified as dangerous (for example, grain).

36. After the exclusion criteria were applied, 430 reports of accidents remained that were analysed in the section below.

### The analysis of the reported accidents

37. The analysis below presents figures on the causes, consequences and lessons learned from accidents associated with ageing.

***Types of ageing phenomena involved in the reported accidents***

38. Out of the 430 accident reports the most commonly cited ageing phenomena, in 45 % of the cases, was corrosion. The second most common factor was due to either fatigue/wear and vibration or the combination of these, accounting for 20% of those reported. Obsolescence and erosion was the third most common phenomena. In half of the cases erosion was reported under corrosion. In 13% of the cases it was not possible to determine which ageing phenomenon contributed to the accident. The distribution of types of ageing phenomena is presented in Figure 2.

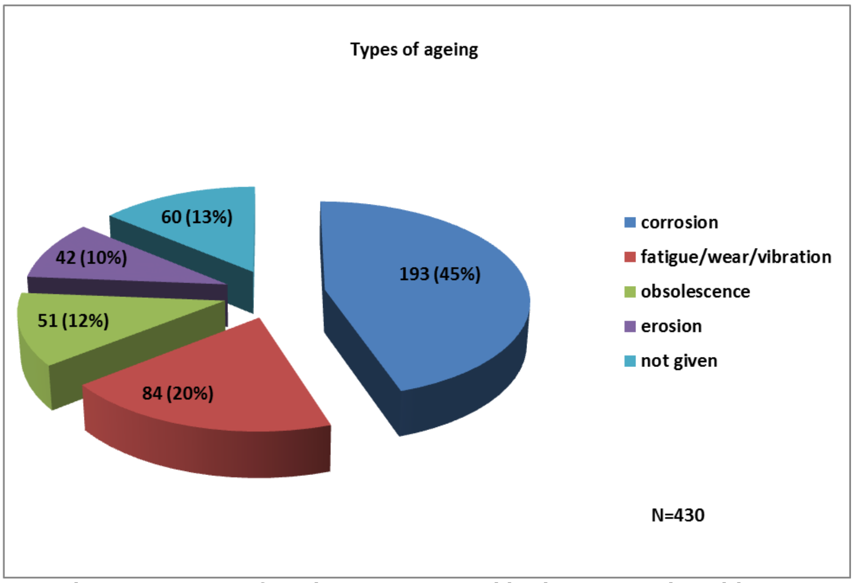



**Figure 2: Types of ageing encountered in the reported accidents**

39. Below are some examples to illustrate these results, directly extracted from the reports that were analysed:

*Corrosion*

"A fire occurred on the C5/C6 Isomerisation plant (Unit 35) at a refinery. Approximately 48 tonnes of naphtha was released from an insulated pipe feeding the dehexaniser fractionating column of Unit 35 and subsequently found a source of ignition. The pipe fed into the dehexaniser column approximately 25 metres above ground. Subsequent examination of the failed pipe revealed that significant corrosion underneath the insulation had occurred on the underside of an elbow of the pipe, just before its entry into the dehexaniser column. At the time of the incident Unit 35 had been taken temporarily off-line and its feed by-passed while planned repair work to the control system of the Unit's Emergency Shutdown System was carried out. Whilst attempting to rectify a fault on the logic system, the programmable logic controllers failed totally on two occasions. The system was re-set after each failure. However, in between the two failures the flow control valve which was situated between the failed pipe and the dehexaniser column, and which controlled the flow of the Naphtha feed into the column, was manually re-set to 15% open, the normal initial setting for starting up the column. This reduction in the valve opening created a greater resistance to sudden flow and hence a higher pressure pulse in the feed line (although still within the design capability of the pipework) when the second start up occurred. It is likely that this increase in pressure found a weakness in the feed line as a result of the corrosion, causing it to rupture and release the naphtha."

*Obsolescence*

". A package of cylinders was being filled with 100% oxygen compressed to 200 bar when a leakage occurred. The leak caused a flash fire, igniting organic material, and leading to serious damage. An employee was struck by the flash fire suffering severe burns to the face and upper body. The valve used to fill the cylinders had degraded faster than had been foreseen by the employer potentially leading to plastic particles detaching from seals in the valve. During filling these particles are 'trapped' in a filter which is incorporated into this valve. When the bottle package is vented, gas flow is reversely guided through the valve allowing these "trapped" and other particles to be carried along with the gas stream. Furthermore, the inside of the hose was corroded (rusted) at the height of the connecting coupling. The hose had not been inspected and maintained. This incident was possibly due to a combination of inadequate equipment (valve), together with the defective flexible hose, lack of adequate personal protective equipment and the lack of a 2nd escape."

### *Fatigue/Wear/Vibration*

"The pipes of a propylene cooler were incorrectly mounted/manufactured (not inserted in the support divisions but "loose" on board) allowing pipes to vibrate, resulting in leaking of propylene into the cooling water side of the heat exchanger. As a result, cooling water was contaminated with propylene that reached the cooling water outlet and evaporated into the atmosphere. Approximately 20 t of gaseous propylene was released. The concentration of the released material was such that the existing systems did not notice the spill. An operator noticed the leak at the outlet of the cooling water channel because the odour threshold (30 mg / m3) was exceeded (not because 10% LEL was reached). A detection system was in place at the cooling water channel outlet however the leak was not detected as the concentration of propylene was lower than the set limit."

### *Erosion*

"An explosion originating in the hydrogen processing unit occurred in a 75,000 barrels-per-day refinery. The explosion resulted from the rupture of a six-inch carbon steel, 90-degree elbow (outside radius) and release of a hydrocarbon/hydrogen mixture to the atmosphere. The vapour cloud ignited within seconds after the rupture at an undetermined point in the facility. A review of process data showed that there were no out-of-range or warning indications relevant to the incident until after the elbow had failed. An inspection after the failure found the line at nearly full design thickness a short distance away from the failure. On these facts, it was concluded that the line failure was the result of the thinning of the Schedule 120 carbon steel elbow due to long-term erosion/corrosion."

## Main consequences of accidents associated with ageing

40. The reported accidents listed consequences for each event that can be grouped into four categories:

- Dangerous materials released;
- Human consequences;
- Consequences to the environment; and
- Financial loss.

41. Half of the 430 cases showed release of significant amounts of dangerous substances to the atmosphere as a consequence of the accident. At least one casualty was reported in 70 of the reported accidents. 63 of the reported accidents led to significant consequences to the environment and 52 led to financial losses. These results are presented in Figure 3.

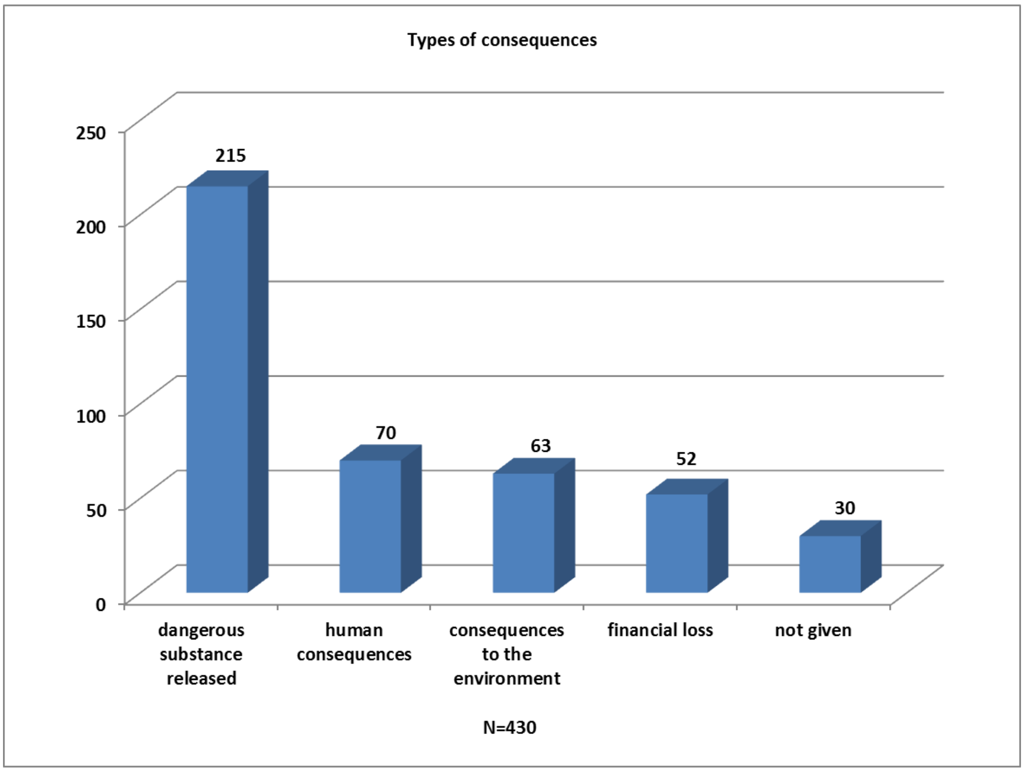



**Figure 3: Main consequences of the reported accidents**

42. The following cases illustrate the most severe consequences amongst the reported accidents, based on each of the above criteria:

***Dangerous materials released***

"A catastrophic failure occurred on a section of pipework on the Saturate Gas Plant (SGP), at an elbow just downstream of a water-into-gas injection point. The 6 inch diameter pipe (the overhead line carrying flammable gas under high pressure) ruptured releasing a huge cloud containing around 90% ethane/propane/butane. About 20-30 seconds later the gas cloud ignited, resulting in a massive explosion and fire. In total, approximately 180 tonnes of extremely flammable liquids and gases were released."

***Human consequences***

"An operator noticed a spot of liquid hydrocarbons in the trench. The leak was localized on a pipeline section 2m from the subway. The company decided to seal the leak by installing a sealing collar on the located rupture point. The workers dismantled the piping insulation (latten and rock wool) in the corresponding pipe section. After the insulation had been dismantled the spill increased with hot hydrocarbons (60° C) spraying downwards towards the subway. As a consequence, a liquid hydrocarbon pool formed and ignited approximately 60m from the leakage point in the pipe. Some hours later a boiling liquid expanding vapour explosion (BLEVE) occurred in another pipeline probably containing light hydro carbons, and was followed by successive explosions of pipelines in the same trench, all due to the overheating of the products inside the pipeline as a result of heat from = the fire in the trench. Fire extinguishing operations lasted 48 hours. The fire seriously damaged the pipelines uphill and downhill the subway, as well as aerial pipelines passing parallel to the trench or crossing it. Further limited damage occurred to the subway. During the accident 4 members of the onsite fire brigade, 2 operators and 8 members of the public Fire brigade were hospitalised for more than 10 days due to burns, contusions and/or poisoning."

### *Consequences to the environment*

"A storage tank containing 16,300 t of 96 % sulphuric acid was ruptured. The entire contents of the tank spilled into the surrounding bund and then out into the nearby dock. When the sulphuric acid came into contact with the water there was an exothermic reaction, which produced a vapour cloud that drifted northwards along the coastline with the wind. After the spill there was approximately 2,000 t of contaminated sulphuric acid by water in the bund. Additionally, around 100,000 square meter of ground surrounding the spill has been affected by the acid."

### *Financial loss*

"A specialized rubber manufacturing facility experienced leakage of a hexane solution from a pump discharge flange during use. Routine operations were being carried out on site at the time of the accident, involving the transfer of a hexane solution from an un-reacted raw material recovery tank to the washing process through the outlet of the first flange of the pump. The flange had been loosened by vibrations from the pump leading to a release of the hexane solution. The hexane vapour was ignited by a static electricity spark and a fire occurred. The financial costs of recovery and lost production were significant."

## Types of industries affected by accidents associated with ageing

43. Amongst the 430 reported accidents, in 192 cases there was an indication of the type of industry that was affected. Almost at equal levels, the general chemical industry and the petrochemical industry were the two most affected industries, representing approximately 30% of the reports. Amongst these 30%, flammable gases or liquids, chlorine or hydrochloric acid were the most significant dangerous substances released. The third most affected industry is in the category of food production where ammonia was the main substance involved. Ammonia was also associated with accidents that occurred in steel, fertilizer and other chemical facilities which were not specified in the reports. These results are shown in Figure 4.

44. The two industry types that were the most affected by accidents associated with ageing are:

1. Production of chemicals;
2. Production of petrochemicals (e.g. oil refineries)

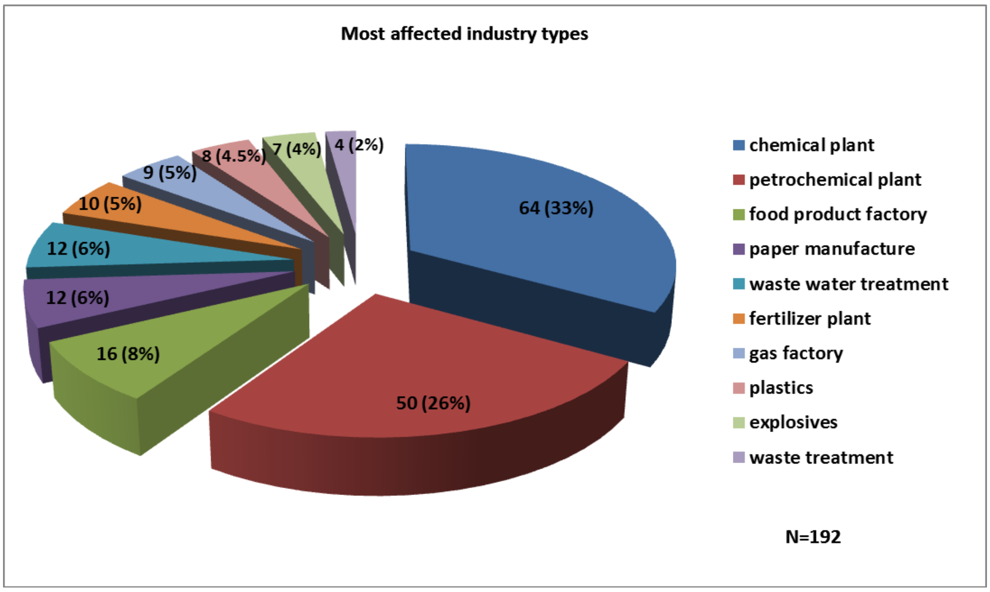



**Figure 4: The most affected industries in the reported accidents**

**Types of equipment affected by ageing phenomena**

45. Out of the 430 accident reports, 217 indicated which equipment failed or suffered from the consequences of the different ageing phenomena. In 45% of the cases pipes were involved (N=98) and in 33% (N=71) storage tanks. In 50% of the accidents involving pipes and storage tanks, the ageing phenomena identified was corrosion. Corrosion was reported as the main cause of failure in 70% of the accidents involving heat exchangers (N=18) and reactor vessels (N=13). The types of equipment involved in the accidents are shown in Figure 5.

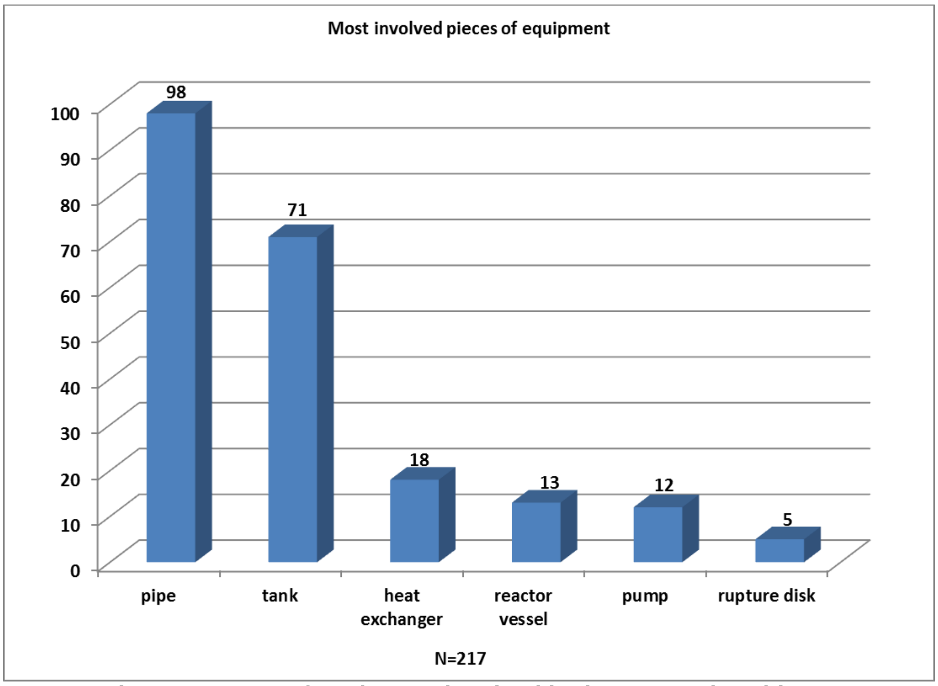



**Figure 5: Types of equipment involved in the reported accidents**

**Main causes for the reported accidents**

46. The first section above presented the most frequent types of ageing phenomena involved in the reported accidents. In many of the reported cases, the technical failure caused by an ageing phenomenon was the result of a failure in one or more elements of the Safety Management System of the facility. It is important to note that in many of the reported cases, either the cause of the accident was not given or if it was, only the direct, technical cause was provided and no human or organisational factors were analysed, or the causes identified were very varied. The most common factors that led to accidents in the reported cases are the followings:

- Lack of oversight of ageing issues by the company: it seems that in some cases the operator failed to monitor equipment subject to ageing even though the affected equipment was regularly used. For example, degradation was cited as the main contributing factor to many accidents, because the operator failed to identify the pieces of equipment particularly subject to ageing.

- Inappropriate design of the equipment: for example the equipment was not resistant to overpressure or metal was not resistant to corrosion at elbows/welds, valve flaw design or the wrong equipment for the chemicals stored was used).

- The absence of proper hazard analysis and risk assessment: it seems that in some cases operators failed to identify hazards associated with ageing for some processes of the site, therefore they were not subject to risk assessment, unlike other parts of the establishment that were considered to be exposed to ageing. This failure is sometimes associated with other failures that cause the facility to ignore or forget critical information that influences risk, such as failure to keep adequate documentation or to manage and document changes.

- A lack of proper monitoring/inspection/audit system: some of the cases highlighted insufficient inspections, both in term of quality and frequency, for critical equipment particularly subject to ageing phenomena. Inspection and maintenance failures can signify that the management does not prioritise timely interventions, or that intervention schedules were based on wrong assumptions, due to lack of a risk assessment or loss of documentation, etc.

**Lessons learned from the reported accidents**

47. Each of these reports specifically identified a particular mechanical failure which is associated with aging. However, reading each of the reports also indicates that there were other contributors associated with failings of the safety, operations and integrity management systems which could be associated with loss of knowledge, documentation and experience.

48. It is interesting to note that the failure of control or safety systems was not identified as a cause or contributor to the severity of the event. Many of these systems may have been obsolete, of a lower standard such as fire and gas detection, or failed to operate effectively. Intuition suggested that these could have been a contributor in some cases but the analysis was not able to highlight it.

49. One of the general conclusions from the analysis is that failure of a piece of equipment due to an ageing phenomena, and which has led to an accident, is most of the time associated with a failure in the safety management system of the facility.

***Organisational and personnel – informing contractors and third party personnel about the functioning and history of the facility***

50. The analysis brought to the fore a number of organisational deficiencies in the facilities where accidents occurred. The reported accidents highlighted, in some cases, issues linked to external personnel being contracted to work at the facility and who did not have proper access to the specifications of the facility and/or who had not been appropriately trained. This raises the importance of assuring that adequate knowledge is transferred to any third party stakeholders involved in the functioning of a facility.

***Operational control – assuring the availability of up-to-date documentation, including as much as possible information on the history of the facility***

51. Some of the reported cases highlighted missing or incomplete documentation on “safety-critical” equipment (for example, tanks, pipelines, pumps). This raises the importance of maintaining up-to-date documentation on all the history of a facility and its equipment (for example, any replacements, additions, past defects). Operators should ensure that policies are in place for determining the end of life date of every piece of equipment and ensure that documentation provides the date for replacement of any pieces of equipment. When determining this date, operators should consider a variety of information including the

frequency and type of use of a piece of equipment and consider how it may be subject to particular ageing phenomena, for example, as a result of possible contact with water, air, intensive use and subject to vibration).

***Audit and review (Inspection) – focusing inspections on critical pieces of equipment that are particularly subject to ageing phenomena***

52. Some of the reported cases highlighted insufficient inspections, both in term of quality and frequency, for critical equipment particularly subject to ageing phenomena. Ageing of critical components can ultimately lead to failure, and therefore, should be subject to a systematic inspection programme. One particular element that was highlighted in some reported cases is the case of underground piping that could lead to specific risk in the foundations and which is particularly subject to ageing phenomena. Process conditions can also accelerate the ageing process, especially corrosion, erosion and fatigue. Stressors that accelerate equipment degradation in certain processes have to also be taken into consideration in the inspection plan.

***Management of Change – conducting risk assessment before changing the way in which pieces of equipment are going to be used***

53. In some of the reported accidents the production levels of older facilities had been increased, leading to an increase in the mechanical stress applied on some equipment, ultimately leading to an accident. This highlights the importance of conducting risk assessment when changes are being planned which may affect the way installations evolve and age, and also to ensure that inspections programmes are reviewed as changes are being applied.

***Monitoring performance – learning from past accidents***

54. In some of the reported accidents a similar incident had already occurred in the same site. Following the initial incidents, no corrective measures were taken, no lessons learned were captured or applied or documentation prepared. This highlights the importance of learning from past accidents and the importance of knowledge transfer over the years to prevent similar accidents recurring.

# THE ROLE OF PUBLIC AUTHORITIES IN ADDRESSING AGEING IN HAZARDOUS INSTALLATIONS

55. A questionnaire was developed in the framework of the OECD Working Group on Chemical Accidents (WGCA) aiming at analysing *(i)* how inspection approaches across countries address the issue of ageing and *(ii)* the role of governments in addressing the potential consequences of ageing in hazardous installations. The questionnaire was prepared and sent to WGCA member delegations in 2014. The following countries responded to the questionnaire: Australia, Belgium, Estonia, Finland, Germany, Italy, The Netherlands, New Zealand, Norway, Slovakia, Sweden, Switzerland, and United Kingdom from different national agencies, which made for a total of 19 respondents.

56. The main results from the analysis of the questionnaires are provided in the section below. It is followed by three illustrative examples from France, Germany and the UK on specific programmes developed to address ageing of installations.

## Inspections approaches and ageing of installations

57. Different questions were posed to countries in relation to their inspection programme and how it integrates the topic of ageing of installations. The results from the analysis for each of the questions are shown below.

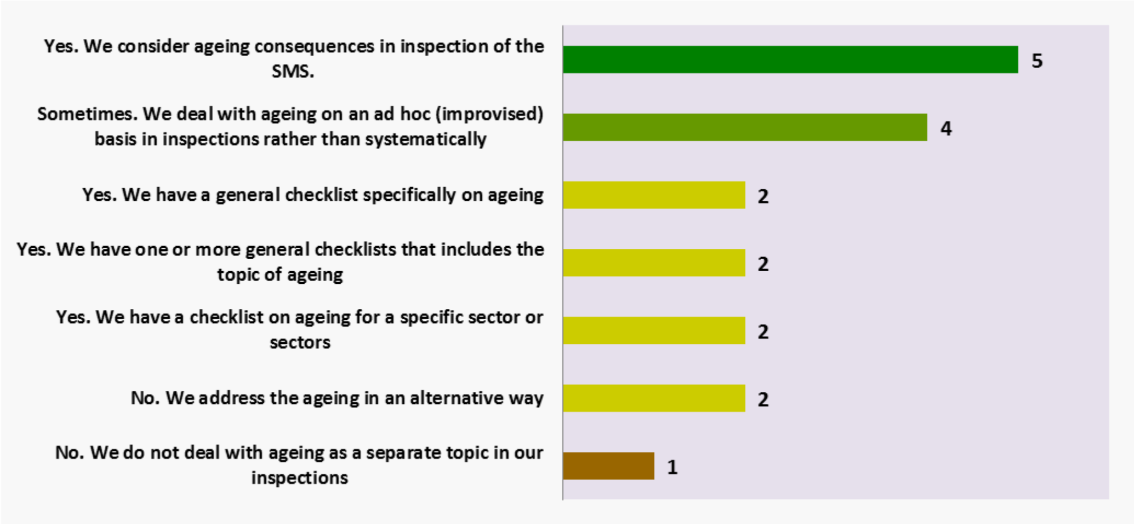
### *Does your authority have an inspection programme designed as specified for the topic of ageing?*

58. This question was answered by eighteen respondents. Five respondents indicated that they had inspection programme specifically looking at aspects of ageing of installations. From the details provided by those respondents, agencies have specific intervention, inspection, testing and maintenance programmes targeting physical degradation processes such as corrosion, however they do not have an inspection programme that encompasses all types of ageing mechanism (that is, degradation, obsolescence and organisational ageing). Some respondents indicated that they conduct inspections on the facility's safety management system in relation to ageing. One respondent indicated that ageing is not specifically addressed in inspection programmes whilst twelve respondents indicated that ageing is partially addressed.

### *Do you have specific questions or check lists that address the topic of ageing?*

59. Out of the eighteen respondents, eleven indicated that they had a procedure in place to address ageing, four to address ageing on an ad-hoc basis and two to handle ageing in a different way. The procedures to address ageing included general checklists as well as specific checklists either on ageing or specific sectors (see Figure 6). From the details of the responses that were provided it can be seen that in some cases checklists are not necessarily strictly followed but rather used to provide general guidance and help the inspectors to ask the right questions.

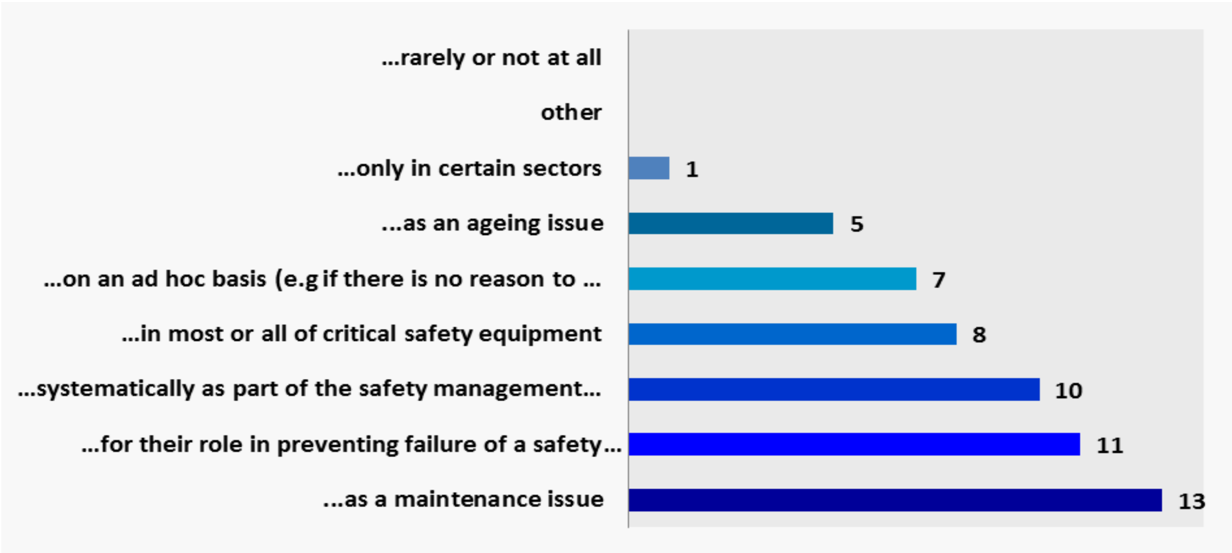
**Figure 6. Availability of specific ageing related questions or checklists**




***In your inspections are degradation mechanisms procedures inspected***

60. Thirteen respondents indicated that degradation mechanisms are inspected as a maintenance issue. One respondent indicated that these mechanisms are inspected only in certain sectors. Eleven respondents indicated that degradation mechanisms are inspected for their role in preventing failure of a safety barrier. Five respondents indicated that degradation mechanism procedures are considered as an ageing issue. In general, it seems that degradation mechanisms procedures are mainly treated as maintenance or a safety issue (see Figure 7).

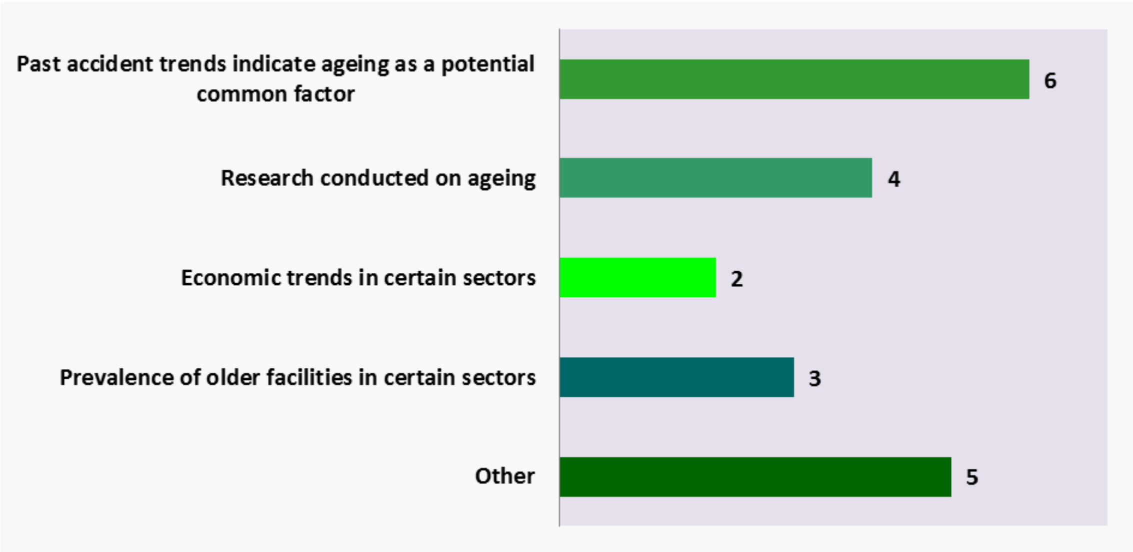
**Figure 7. Availability of methodology to inspect degradation mechanism procedures**



***Why were these interventions introduced?***

61. Thirteen respondents answered this question. In most cases interventions were introduced because past accident trends indicated ageing as a potential contributing factor. Another frequently mentioned reason is that interventions were introduced because research was conducted on ageing (see Figure 8).

**Figure 8. Reasons for introducing ageing intervention**




***Does your programme attempt to judge the general performance of industry in managing ageing issues? If so what is the current view of performance?***

62. Nine respondents answered this question. Six respondents indicated that their programme does attempt to judge the general performance of industry in the management of ageing issues.

***Has your programme identified any general weaknesses in industry's response to ageing***

63. Ten respondents answered this question. Overall, respondents identified that those facilities that outsource ageing management activities have a poorer performance compared to facilities using in-house capabilities. For example, in the case of outsourcing, the testing of safety instrumented functions seems often incomplete or not undertaken. Another issue identified is that documentary evidence of maintenance history is often lacking, unclear or incomplete.

64. Overall, there seems to be difficulties for implementing maintenance and monitoring programmes addressing corrosion under insulation. Uncertainty surrounding the long term use of the components has led to negligent repairs in many cases.

**Countries approaches to manage the consequences of ageing**

65. Different questions have been posed to countries in relation to their approaches to manage the consequences of ageing. The results from the analysis for each of the questions are shown below.

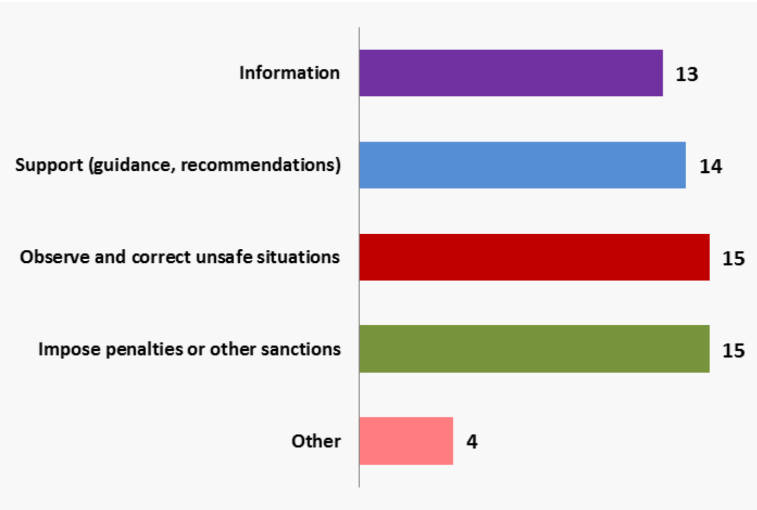
***What is the role of the government in addressing the potential consequences of ageing in hazardous installations?***

66. Nineteen respondents answered this question. Overall, from the respondent's answers, the most frequent actions used by governments to address the potential consequences of ageing are:

- Firstly: “Observing and correcting unsafe practice” and “Imposing penalties or other sanctions”;
- Secondly provide “Support (guidance, recommendations)” and “Information”.

Nine respondents indicated that they combined the four actions together.

**Figure 9. Governments’ measures in addressing potential consequences of ageing**




**How your country addresses the potential consequences of ageing in hazardous installations**

67. This question aimed to identify the authorities responsible for different types of installations, and the scope of the country’s regime.

68. Fifteen respondents provided a response regarding the responsible authorities in charge of the following installations: “General”, “Storage tank”, “Onsite pipe work”, ”Civil engineering structure”, “Buildings”, “Transportation pipelines”, “Nuclear facilities”, “Offshore facilities”, “Process reactor vessel”, “Control & instrumentation systems”, and “ other". Overall, responses indicated that across industry sector and type of installations, none were the responsibility of a single agency. The responsibility for the facilities is split under different government agencies.

69. Regarding the question on how ageing is addressed by authorities: through "Inspection", "Regulation", "Recommendation/Guidance" and "Other". “Inspection” and “Regulation” appear to be the most common way to address ageing across installation types. Ten respondents indicated that they use “Recommendations/Guidance” and seven reported using “Other tool". Regimes used in each installation are shown in Figure 10 and Table 4.

**Figure 10. Tools used by authorities to address ageing across installation types**


**Table 4. Tools used in the different types of installations**

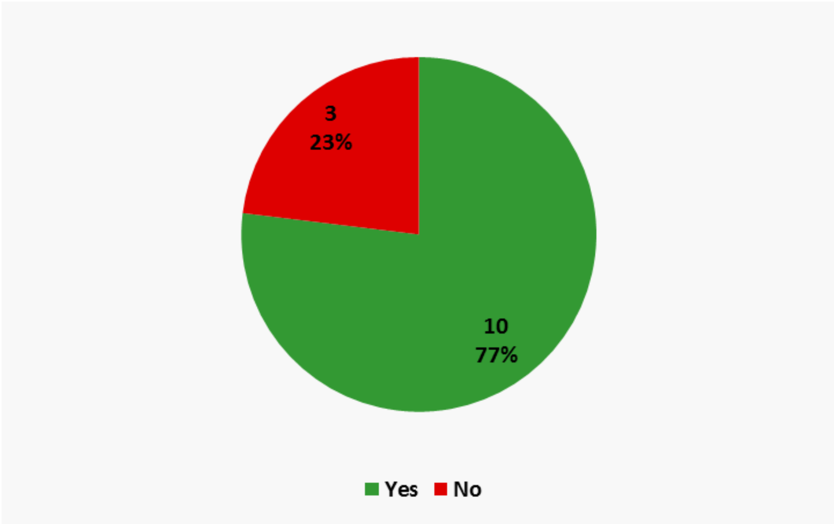
| | General | Storage tanks | Onsite pipework | Civil engineering structure | Building | Transportation of pipelines | Nuclear plant | Offshore facilities | Process/ reactor vessel | Control instrumentation systems | Other | *Industrial areas / equipment covered* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Regulation | 11 | 11 | 11 | 4 | 3 | 9 | 3 | 5 | 9 | 4 | 2 | *11* |
| Recommendations/Guidance | 7 | 11 | 5 | | 1 | 1 | 3 | 5 | 5 | 3 | 2 | *10* |
| Inspection | 11 | 11 | 10 | 3 | 4 | 10 | 4 | 5 | 10 | 4 | 3 | *11* |
| Other tool | 3 | 2 | 1 | | | | 1 | 1 | 1 | 2 | | *7* |

Key: the numbers in the table correspond to the number of respondents having chosen this answer.

***Does the programme consider issues such as the role of the organisation's leadership and resourcing in managing ageing?***

70. Thirteen respondents answered this question. Ten respondents indicated that their programme consider the role of the organisation's leadership and resourcing in managing ageing (see Figure 11).

**Figure 11. Leadership and resourcing in managing ageing**




## Examples of programmes addressing ageing of installation

### *The United Kingdom*

*Background*

71. The United Kingdom developed a specific project on Ageing Facilities at Seveso sites[7]. It is managed by the Chemical Explosives and Microbiological Hazards Division (CEMHD), which is responsible for the regulation of the onshore chemical and petrochemical sector and as such responsible for all sites regulated under the Seveso Directive. In the UK ageing plant was introduced as a strategic priority in April 2010.

72. The implementation of the Control of Major Accident Hazard Regulations (COMAH) in 1999 (implementing the Seveso II Directive) brought about a change in approach to regulation of onshore major hazards. Previously Regulatory Inspectors were the primary contact with a site with Specialist Inspectors only called in where additional expertise was needed, and usually on a reactive basis. The application of the new regulations introduced a new model where specialist inspectors could carry out proactive inspections within their discipline. Key disciplines were listed as: Process Safety, Mechanical Engineering, Electrical Control and Instrumentation. Human Factors was added at a later stage.

73. In the UK, between 2000 and the introduction of the Ageing Plant programme, Mechanical Engineers focused principally on the management of the integrity of the primary containment boundary in a facility, looking for technical failures and having them fixed. Around 2006, Mechanical Engineers inspectors were increasingly noting that many of the sites they visited were old and began considering whether they warranted a different approach to inspection. This led to the commissioning of the HSE

7 A separate programme exists targeted at the offshore sector that concentrates on plans for dealing with end of design life issues.

Research Report 509 'Plant Ageing'[8]. The work carried out through this research report allowed for the development of the now accepted definition of 'ageing' in the UK which we saw in the first section of this report. Ageing is defined as "the degradation of equipment from its new condition". The research report also stressed the importance of monitoring (and acting on) plant condition throughout its life.

74. In 2008, further work on ageing plant was commissioned looking beyond purely mechanical engineering and technical aspect to include, in particular control systems and management functions. The work also looked at the UK and European data to provide evidence that ageing was a significant contributor to major accidents and losses of containment that had the potential to lead to major accidents. This report was the research report 823 – Plant Ageing Study[9]. Following a major review of the way in which the COMAH Regulations were enforced in the UK (COMAH Remodelling) the concept of Strategic Priorities – that is topics critical to the prevention and/or mitigation of major accidents – were introduced. Ageing Plant was one of the earliest Strategic Priorities introduced in 2010. The key difference between this and what had gone before was the broadening of focus beyond the purely technical to include topics such as leadership and resourcing – the objective being to identify and correct root causes of technical failings – and so prevent recurrence.

75. The Seveso III Directive, which came into force in EU Member States on 1 June 2015 includes the concept of ageing plant for the first time and specifically lists it as a topic for consideration as part of the development of an establishment's Safety Management System.

*The UK's ageing plant programme*

76. The UK's Ageing Plant Programme consists of two key elements: the intervention programme; and the engagement with stakeholders.

77. The Intervention programme covers a broader range of topics and aims to establish root causes of technical problems via a structured approach led by specialist mechanical engineers. The plan requires looking at leaderships and resourcing issues and gives an increased importance to maintenance regimes (in addition to inspection regimes). Through this plan, the aim is to cover most Seveso sites in the UK, acknowledging that some installations such as warehousing are less likely to have ageing plant issues. The performance of each site is scored against 5 key topics:

- *Leadership*: Senior managers' knowledge of and attitude to ageing issues
- *Asset register:* Does the site know what equipment it has and which of it is safety critical?
- *Primary Containment*: Management of the integrity of the primary containment boundary
- *Safety Critical Mechanical Equipment*: Maintaining safety critical equipment, such as pumps, compressors etc.
- *Resources*: Availability of sufficient competent resource to manage ageing issues

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8 United Kingdom Health and Safety Executive (2006), Research Report 509 – Plant Ageing http://www.hse.gov.uk/research/rrhtm/rr509.htm

9 United Kingdom Health and Safety Executive (2010), Research Report 823 – Plant Ageing Study, http://www.hse.gov.uk/research/rrhtm/rr823.htm

78. Each topic gets a performance score between 10 (excellent) and 60 (unacceptable). Scores are aggregated nationally to create a countrywide performance picture:

- Between 10 and 20 = Green (compliant);
- 30 = Amber (Partially compliant); and
- 40, 50 & 60 = Red (unacceptable).

79. Structured interventions are made by inspectors looking at specific topics. Legally binding actions, where necessary, are put in place at the end of a visit and are followed up to confirm completion. More significant problems can be tackled through formal enforcement such as Improvement Notice. In serious situations a Prohibition Notice can be used to stop equipment immediately (or require its safe run down as soon as possible). A prohibition notice under COMAH can be used in the absence of key risk control systems and so does not require an opinion of immediate risk of serious injury. An example could be the lack of a system for ensuring plant integrity where hazardous materials are present. A system of prioritisation exists to ensure that highest hazard sites are given the highest priority. All sites received an initial intervention within the first couple of years, and would expect further interventions to drive improvements and ensure performance does not diminish over time.

80. The Stakeholder Engagement phase dealt with communicating on the ageing programme directly with industry. A significant level of resource was committed with up to 16 events organised in the first two years. The aim was to approach directly industry stakeholders looking for opportunities to present at their own events. This was a successful proactive approach, which led to a high level of awareness of ageing and its significance to the industry. In addition to present the overall programme, a number of events were organised on specific technical issues. An example is the increasing use of non-invasive inspection techniques (as the name suggests carrying out examinations without having to go inside the equipment). This has great attractions in terms of cost and time savings but needs to be applied carefully in order to make sure the techniques used are capable of finding the damage that needs to be found. There was also direct collaboration with industry to produce guidance on specific issues. This close collaboration with industry allowed the regulator to secure rapid acceptance and take-up by industry in general and ensured the guidance drew on practical industry experience increasing its quality and usefulness.

*Progress to date in the application of the programme*

81. The plan was applied to 500 of a total of around 800 Seveso sites in the UK. The performance data gathered provided strong evidence for areas that needed special attention. This evidence gathering provided good ammunition to ‘prove’ there was an issue to be tackled regarding ageing of installations and allowed raising awareness on ageing related issues to senior leaders. This is particularly important in a time when use of resources needs to be well justified.

82. A deeper analysis of the performance data indicated a particular issue with the use of external bodies for examination. There is significant difference in performance in industries that predominantly use in-house resource versus those using external contractors in integrity management. This led to development of two significant guidance documents:

- The mechanical integrity of plant containing hazardous substances - a guide to periodic examination and testing[10]: this was developed in 2012 by HSE together with Trade Associations

10 For more information, see https://www.eemua.org/Products/Publications/Digital/EEMUA-Publication-231.aspx or http://safed.co.uk/technical-guides/pressure-equipment/

for external examination bodies and representatives of in-house bodies. This guide covers all aspects of examination, including management and execution.

- Use of External Contractors in Managing Ageing Plant[11]: this guide was published in 2015 by HSE together with the Chemical and Downstream Oil Industries Forum (CDOIF). It specifically addresses the interface between client and contractor. The key message from the guide developed the concept of the “intelligent customer”: although a site may not have the resource to carry out the ageing management work themselves they must assure that a person in-house has the expertise to know what will be required from the contractor, and verify that the contractor delivers what is required.

***France***

83. In 2010, the French Ministry of Ecology and Sustainable Development launched a modernisation plan for its industrial facilities, potentially targeting about 10000 facilities in the country. The plan aims to address in a systematic way environmental risks associated to ageing installations. The development of this plan originated from the implementation of lessons learnt from a number of accidents linked to degradation mechanisms that occurred in the country in the past years.

84. The modernisation plan is focusing on a number of equipment types, in particular:

- Civil engineering work;
- Safety instrumented systems;
- Storage tanks;
- Transmission pipelines; and
- Capacities and pipes.

85. The modernisation plan has been implemented directly in the French regulation with a number of decrees that have been developed corresponding to each of the equipment types mentioned above. A transversal action is being taken across equipment types to adapt, when necessary, the safety management system of the facility so that it reflects ageing of installations related concerns.

86. The plan first identified the pieces of equipment in the country that are subject to the highest technological and environmental risk. The operators of the identified facilities were then required to develop a specific dossier including:

- A description of the initial condition of the concerned pieces of equipment;
- A strategy to monitor the degradation of equipment from its initial condition over time and an action plan for follow-up on any specific issues that can be found during the inspections.

87. The dossier should include a report of the results of the inspections conducted and a description of any follow-up actions that have been taken as a result of inspections. To support operators, the French

11 For more information, see http://www.hse.gov.uk/aboutus/meetings/committees/cif/resources.htm

public authorities have issued a number of professional guides[12], each corresponding to a specific type of equipment. The guides define, for example, the major environmental risk that can result from the use of a particular type of equipment under particular condition. They explain the possible degradation mechanisms that can affect equipment and detail the procedures for establishing the initial condition of a particular type of equipment. They can define a number of control points, and propose control methods as well as indicate the frequency of inspections needed. In the absence of compliance with the professional guides, provisions are set up by default. These professional guides have initially been developed by industry associations; they are then reviewed and validated by the French public authorities with the support of an expert working group. The guides are published in the official bulletin of the French Ministry of Ecology and Sustainable Development.

88. The plan came with specific timetables that differ for each type of equipment. For example, for capacities and pipes that were put in service before the 1st January 2011, the initial condition had to be established before the 31st of December 2012. An inspection programme had to be put in place before the 31st December 2013.

***Germany***

89. In Germany, establishments that can cause major accidents are subject to the Major Accident Ordinance[13]. This ordinance includes in Article 3, Paragraph 4 the following obligation for operators:

*"(4) The nature and operation of the installations in the establishment must be in keeping with the state of the art of safety technology."*

90. If the nature or the operation of an installation is not according to the art of safety technology, either because the safety technology has developed or because there was degradation due to aging, it's the obligation of the operator to take the required measures to bring the nature or operation of the installation into compliance with the art of safety technology again.

91. This obligation is enforced at existing installations in licensing procedures, in case of relevant modifications, and inspections, especially in case of accidents. Authorities can use this regulation in inspections programs according to Article 16 of the Major Accident Ordinance to require from operators further measures to monitor ageing of installations and to take required "Anti-Ageing" measures. Aging may be the special subject of inspections programs defined according to Article 16 of the Major Accident Ordinance.

12 See more information on the French Modernisation Plan and all the professional guides developed so far on the website of the French Chemical Industry Association at, http://www.uic.fr/Activites/Securite-industrielle/Plan-de-modernisation (in French)

13 For more information please see, http://www.cgerli.org/fileadmin/user_upload/interne_Dokumente/Legislation/stoerfallv_engl1.pdf

## CONCLUSIONS

92. The main conclusions from the report are highlighted below:

- Ageing does not only refer to physical ageing, it also include all the other elements of a plant that can be subject to ageing and have an impact on safety, such as ageing of people, procedures and technologies. As such ageing should be considered as general topic area, not something that is specific, for example, to mechanical engineering;

- It is important to acknowledge the changing landscape in the chemical sector in the last 50 years and its impact on ageing phenomena;

- Ageing is often one of a number of factors involved in an accident;

- There is a great importance of record keeping to manage ageing phenomena - including having up-to-date documentation on the history of the plant, monitoring entry into service and use of pieces of equipment particularly sensitive to ageing phenomena. As seen in the report, particular attention should be given to facilities that have been through a change of ownership to assure record keeping and a continuation of understanding in the plant process.

93. Research done within the context of this project raised a number of questions that could be addressed in future activities:

- Is there any additional research required to improve understanding of ageing of installations?

- Is there a need for new specific guidance on ageing management, in particular, that would include ageing of non-mechanical systems?

- How can ageing be best addressed in enforcement activities like inspections or review of licences?