THE IMPORTANCE OF RECOGNISING AND MANAGING AGEING PLANT

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Onshore process and chemical plant is ageing. This can lead to leaks and failures which impact on safety, health and the environment as well as business performance.

To help inform and prioritise their approach to the topic of ageing plant, the Health and Safety Executive contracted ESR Technology to conduct an extensive analysis and review of various UK and European-wide accident and incident data to assess the extent to which ageing mechanisms are contributing to accidents and losses and to provide a technical basis to identify, target and prioritise the key issues associated with ageing plant.

This paper presents the findings of these analyses and reviews to show the significant contribution of ageing mechanisms to accidents and losses and the lessons that can be drawn from this data. It shows how these findings were used to develop a broader approach to, and definition of ageing plant which is now being taken forward by the COMAH Competent Authority[1] as a Strategic Priority for the targeting of interventions at COMAH sites.

To quote a key conclusion from the study: "An analysis ... has shown that across Europe, between 1980 and 2006, it is estimated that there have been 96 incidents reported in the MARS database relating to major accident potential loss of containment which are estimated to be due to ageing plant. This represents 28% of all reported 'major accident' loss of containment events in the MARS database, approximately 50% of all technical integrity and EC&I related incidents, and equates to an overall loss of 11 lives,183 injuries and over 170 Million € of economic loss."

Ageing is not about how old your plant and equipment is; it is about its condition, the service it is in and how that is changing over time. The issue of ageing industrial assets is of increasing importance to regulators and the industry as a whole, as its successful management is critical to the overall safety performance of process plants.

Although the study was commissioned by the UK Health and Safety Executive, it has implications not just for the UK, but for Europe as a whole. It is hoped that this paper will promote the need to recognise and manage ageing plant and help industry better understand the basis of HSE's approach to this topic and HSE's concerns regarding this issue.

WHY AGEING PLANT?

Onshore chemical plant in the UK is ageing. This can lead to leaks and failures which impact on safety, health and the environment as well as business performance.

Health and Safety Executive (HSE) field inspectors often have to consider the Operators' safety justification for continued use of ageing plant taking account of a variety of issues such as usage, design life, known research, known operational and failure history, maintenance and inspection history, etc. The issues also need to be considered against a background of increasing competition from overseas, and the pressure on resources and investment which this has had over recent years, with reductions in manning levels, early retirement of experienced staff, and pressure on operating budgets.

The importance of plant ageing has been long recognised and HSE Research Report RR 509 "Plant ageing: Management of equipment containing hazardous fluids or pressure" (Wintle et al., 2006) comprehensively describes a number of key issues associated with ageing plant but its findings are not targeted with recommendations to inform field inspectors when prioritising intervention and enforcement strategies in the field. HSL Report PS/07/06 "Guidance on fire and explosion hazards associated with ageing offshore installations" (Dalzell, 2007) is more targeted at dealing with the problems but focuses on offshore oil and gas installations.

To help inform and prioritise their approach to the topic of ageing plant, the Health and Safety Executive contracted ESR Technology to conduct an extensive analysis and review of various UK and European-wide accident

[1]The COMAH Competent Authority is made up of the Health & Safety Executive together with the Environment Agency (England) and the Scottish Environmental Protection Agency (Scotland).

and incident data to assess the extent to which ageing mechanisms are contributing to accidents and losses and to provide a technical basis to identify, target and prioritise the key issues associated with ageing plant.

The key question is simply "Is there a problem?". Following from that are questions concerning the nature of the problem and whether there is any evidence to show that certain areas of the UK industry are more susceptible than others. To answer these questions ESR have examined a number of data sources with a view to identifying those incidents which can be attributed to plant ageing issues.

THE APPROACH TO THE ANALYSIS

An approach was adopted that deliberately expanded the scope of ageing plant to ensure a focus on all the relevant aspects critical to managing major accident hazards, and not just the more obvious primary containment and associated structures. The aspects considered were expanded to include:

- Primary Containment Systems
- Electrical, Control and Instrumentation (EC&I) Systems
- Structures
- Safeguards
- Management Systems

The methodology adopted was to develop a series of "Main Issues" and "Specific Issues" for each asset category that can be affected by ageing and could potentially give rise to significant incidents. These specific issues were derived from the direct experience of a range of HSE Specialist Inspectors and ESR consultants. The issues were examined against three principal databases of incident reports and a collation of incidents from various sources under voluntary reporting arrangements:

- Reportable Injuries, deaths and Dangerous Occurrences Regulations Database (RIDDOR) (operated by the Health & Safety Executive)
- European Union Major Accident Reporting System (MARS) (operated by the European Commission Joint Research Centre)
- Major Hazard Incident Data Service (MHIDAS) (operated by AEA Technology on behalf of the Health & Safety Executive)
- UK onshore chemical and major hazard industries voluntary reporting of loss of containment incidents (HSE 2004, HSE 2005, HSE 2006, HSE 2007, HSL 2003)

The databases of incident reports were reviewed thoroughly and incidents with ageing aspects, in each of the asset categories, were identified using keywords contained within the incident text descriptions. It should be noted that the text information contained in the databases exhibited a very large variation in the level of detail provided within the reports. The degree of variation essentially rendered semi-automated keyword searching of little use and the only practical way to proceed with the analysis was to manually consider each report in detail and make a judgement on whether or not ageing was a contributing factor in the incident.

The objectives of the database reviews were to:

- Provide an indication of the size, if any, of the ageing problem.
- Identify issues that are of importance in plant ageing in the various asset categories used in the study.
- Identify issues that had not been recognised.
- Provide information on how the identified issues might be suitably prioritised.

FINDINGS OF THE DATA ANALYSES – HOW IMPORTANT IS AGEING?

Examination of the incident reports in the three primary data sources indicated that in two of them, i.e. RIDDOR and MHIDAS, it was difficult to positively assign ageing issues in many cases. This is because the reports are either very brief or do not reveal the root causes of the incidents. For example:

> *"Explosion of valve in oxygen line – This was second explosion of valve in exactly same position in 12 months. Back pressure valve between oxygen vaporiser and filling line, holds 100 bar upstream to reduce velocity through vaporiser. Located where no normal access, so low risk. Previous incident last year - no obvious cause as most of valve consumed in ensuing fire. Investigation continuing."*

The explosion in this example may or may not have been caused by an ageing issue.

Unfortunately, in attempting to answer the question of whether or not ageing is a problem, such incidents have the effect of diluting the statistics. They therefore have the potential to skew the statistics in either direction depending upon whether they are included or excluded from the assessment. In terms of uncertainty in the data analysis, it was concluded that the limited descriptive data provided in the RIDDOR and MHIDAS databases means that a considerable degree of judgement had to be used to assess if a given event was in any way ageing related. This included reviewing the textual descriptions for mention of specific ageing mechanisms, or failures that could be attributed to ageing, or other information on the context that indicated that ageing was a factor. If none of these were specifically present, then the incident was not classified as ageing related. Further uncertainty is introduced in the RIDDOR data owing to the short timescales required to send the incident reports to HSE before proper investigation of the root causes can sometimes be completed. The data analysis should therefore be treated with some caution. It is likely that if more detailed and considered data were available, this would show that more incidents were in some part ageing related, so the extent of ageing failures may be higher than estimated in this analysis.

The data received from the MARS system contains substantially more detail than that routinely kept in the other two principal sources. As such it is possible to have significantly more confidence in the assignment of issues to individual reports, and hence have more confidence in the resulting statistics. It should be noted however, that while the RIDDOR and MHIDAS data are of less use in identifying the size of the potential ageing issue they do contain substantial numbers of reports that can be associated with the identified issues and therefore provide extremely valuable information concerning the nature of the ageing processes.

The MARS database provides significantly better information, though by no means fully comprehensive. This has allowed specific causes such as corrosion, fatigue, vibration and erosion to be identified. These mechanisms for containment or structural failure can be classified as ageing related with a high degree of confidence. However, it has been more difficult to determine which EC&I, non metallic structural, safeguards or health, safety and environmental management system failures related to ageing. The findings for these latter categories should be treated more cautiously as a degree of judgement was required to assess if ageing was an issue, since in many cases the data did not provide any key text that would confirm ageing as a definite causation factor.

Analysis of the MARS data showed 348 reports. Of these, 54 of the reports have uncertain or missing causative factors leaving a total of 294 incidents that could be fully analysed.

Figure 1 indicates the proportion of these incidents that could be broadly categorised as due to Technical Integrity issues, EC&I issues or Human Factors/Procedural type issues. This indicates that approximately 60% of the MARS incidents are Technical Integrity or Electrical, Control and Instrumentation (EC&I/C&I) related.

The Technical Integrity category is of particular interest to this study as it should reflect the state of the containment, supporting structures and engineered (physical) safeguarding systems. The breakdown of causes of these incidents is illustrated on Figure 2.

Combining the Technical Integrity Incidents with the EC&I related events and assigning those events identified as being caused by ageing issues leads to Figure 3.

This analysis indicates that approximately 50% of Technical Integrity and EC&I related incidents are age related. Given the uncertainties in the analysis a broad assessment of the size of the ageing problem may be made by the statement:

> *"60% of 'potential major accident' incidents are Technical Integrity or Control and Instrumentation related issues and 50% of those are associated with ageing of one type or another".*

This shows that ageing mechanisms are a key factor in the causation of major accident incidents, and are the leading cause of losses of technical integrity.

These findings are broadly in accordance with previous HSE research. For example 'Findings from Voluntary Reporting of Loss of Containment Incidents 2005/06′ (HSE, 2006) state that 50% of accidents are caused by incorrect operator action and 22% are caused by equipment/plant failure. Corresponding figures for 2004/05 (HSE, 2005) are 37% operation and 32% plant failures. However, it should be noted that the HSE data reflects a wider range of loss of containment incidents, not just those of major accident potential from a COMAH/Seveso II site. Therefore it is to be expected that the MARS data may show a higher incidence of technical integrity failures compared to RIDDOR.

The full report RR823 (Horrocks et al., 2010) provides more detailed findings from the review including those from analysis of the RIDDOR and MHIDAS reports. It presents asset specific analyses to establish the nature of the incidents and their specific causes.

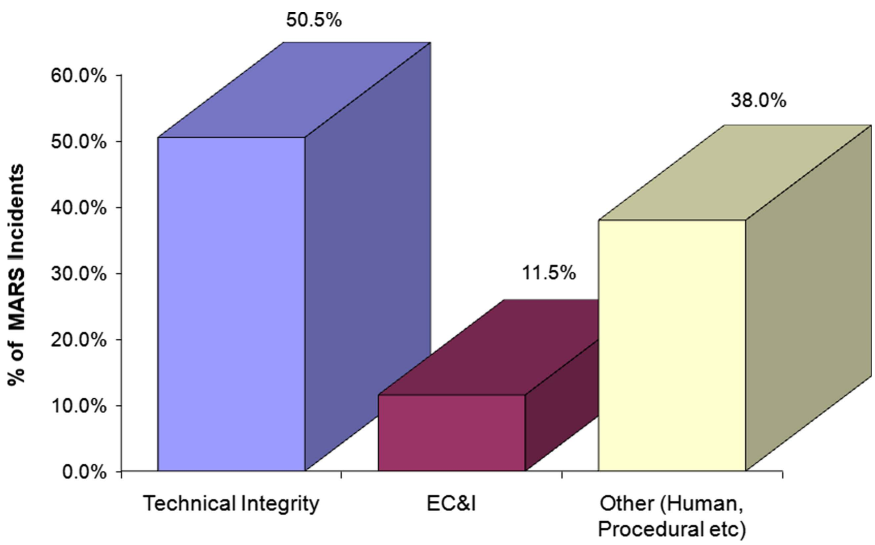

Figure 1. High Level Categorisation of MARS Incidents

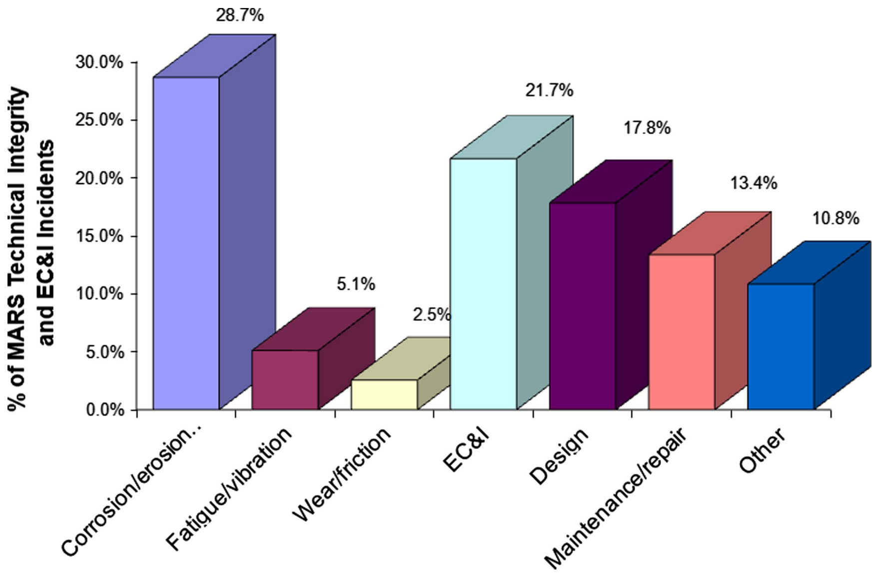

Figure 2. Causes of Technical Integrity Incidents in MARS data

SAFETY, ENVIRONMENTAL AND ECONOMIC IMPLICATIONS OF AGEING INCIDENTS

The MARS database also provides estimates of the severity of the incidents in terms of their human, ecological and financial impacts. This information has been used to assess the impacts arising from ageing related incidents. The findings are summarised in Tables 1–3.

The total economic losses for the incidents are presented in Table 3. The average economic loss per ageing incident (averaged across all 96 ageing events) is 1.8 M €. The highest average is the average for ageing related containment integrity failures at 2.6 M €. This compares with the average loss across all MARS incidents (348 events) of 2.3 M €.

From these tables we can conclude that ageing incidents are perhaps no different with respect to deaths/injuries compared to the overall data for all accident causes, but when ageing related losses do occur, these have relatively high associated costs and disruptive impacts on local communities.

The averaged cost impacts of all 'ageing' incidents are shown to be slightly lower than for the 'average' incident. This may be due to the fact that some of these incidents may be localised and readily fixed. However, the average

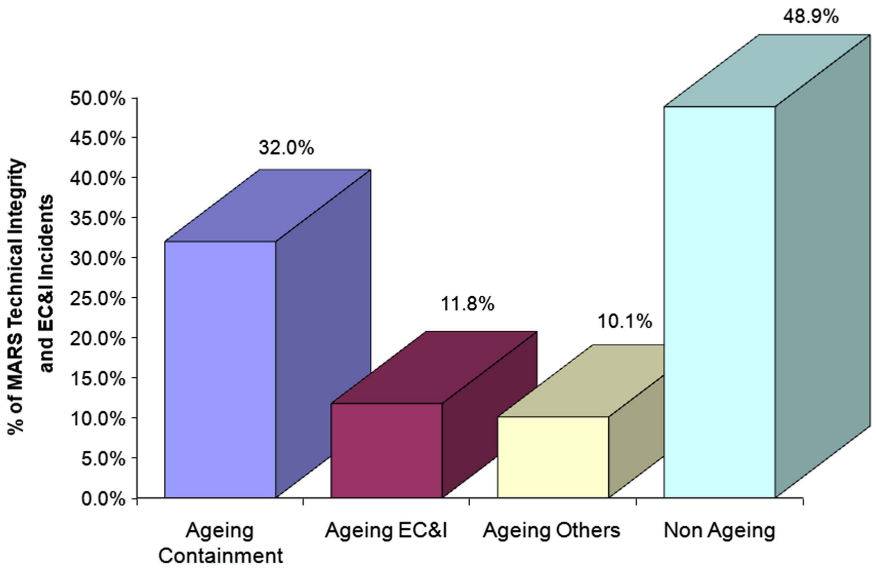

Figure 3. Proportion of MARS Technical Integrity Incidents and EC&I Incidents with Ageing as the Cause

Table 1. Deaths and Injuries Statistics for MARS Reportable Major Accident Hazard Incidents

Class	Total No. Incidents	Deaths			Injuries		
		No. Incidents	Total No. Deaths	Deaths Per Event	No. Incidents	Total No. Injuries	Injuries Per Event
All Events	348	57	124	2.2	140	4201[1]	30.0
(Excluding[1])					139	1959	14.1
All Integrity	149	11	35	3.2	51	768	15.1
Integrity ageing[2]	57	3	4	1.3	21	125	6.0
C&I ageing[3]	21	2	4	2.0	4	32	8.0
Other ageing[4]	23	2	3	1.5	7	47	6.7
All ageing[5]	96	7	11	1.6	30	183	6.1

Notes:
[1]One incident with 2242 injuries.
[2]Ageing from corrosion, erosion, stress corrosion cracking, fatigue, corrosion fatigue, vibration and wear.
[3]Ageing where C&I is a factor.
[4]Ageing from other sources (safeguards, structural, etc.).
[5]All ageing sources (this total is 5 less than the sum of the three above categories as 5 of those incidents are 'double counts' since classified in two or more ageing categories from[2,4]).

cost impact for ageing containment integrity (Integrity ageing) incidents is higher than that for the 'average' incident. This probably reflects both the economic impact of the plant outage and repair costs of significant leaks, and the fact that some of the more serious leaks would have escalated, causing widespread damage to the plant. Major leaks and escalating events arising from containment failures may also explain the higher incidence of community impact associated with ageing events.

Some key ageing issues identified related to specific types of asset/equipment are highlighted in the following sections.

EQUIPMENT MANUFACTURED FROM NON-METALLIC MATERIALS

It should be noted that some primary containment equipment is manufactured from non-metallic materials. RR509 (Wintle, 2006) touches on these and the general principles still apply. However, there may be a perception within industry that such materials are not susceptible to age related degradations. This type of equipment is considered specifically here in order to determine whether or not there is a need for a different approach to management of ageing.

Composite materials have been used in chemical, processing and refinery applications for close to 40 years primarily in containment applications. The benefits are their perceived corrosion resistance and good strength to weight characteristics. The composite materials used in this industry is primarily glass fibre reinforced plastic (GRP). A variety of glass fibre types and resins may be used dependent on environmental and conditions.

Composites are tolerant materials provided that the correct resin and fibre types have been selected and the components are properly installed. Material selection in corrosive environments is a specialist area and end users are reliant on service experience and advice from equipment manufacturers.

Composites do not corrode per se but can be subject to a number of degradation mechanisms including physical ageing, mechanical ageing and chemical ageing. The consequence of these can be a reduction of 20–40% or greater in

Table 2. Incidents involving Ecological Impact, Material Loss and Community Disruption for MARS Reportable Major Accident Hazard Incidents

Class	Total No.	Ecology Impact No.	Incidence of Ecology Impact	Material Loss No.	Incidence of Material Loss	Community Disruption No.	Incidence of Community Disruption
All Events	348	64	18%	224	64%	80	23%
All Integrity	149	26	17%	95	64%	37	25%
Integrity ageing	57	11	19%	35	61%	17	30%
C&I ageing	21	4	19%	10	48%	3	14%
Other ageing	23	4	17%	16	70%	3	13%
All ageing	96	18	19%	58	60%	23	24%

Table 3. Total losses (Million € equivalent) for MARS Reportable Major Accident Hazard Incidents

Class	Total Losses (M €)	Incidents Where Loss (No.)	Average Loss per Event (M €)	All Incidents (No.)	Average Loss per Event (M €)
All Events	794.7	107	7.4	348	2.3
All Integrity	329.1	42	7.8	149	2.2
Integrity ageing	149.7	18	8.3	57	2.6
C&I ageing	17.8	7	2.5	21	0.8
Other ageing	3.6	4	0.9	23	0.2
All ageing	171	28	6.1	96	1.8

the strength characteristics of the polymer during the lifetime of the component and introduction of damage including matrix cracking and delamination.

Design codes use regression curves based on short term and longer term (typically 1000 h) immersion tests to determine the qualification pressure for the component and the allowed operating pressure over the design life. However, there are limitations in the testing methods used: most studies are in water rather than organic solvents or the other fluids/chemicals that are seen in service, and many accelerate ageing by testing for a shorter time (~1000 h) at a more elevated temperature. A concern therefore is whether the methods of life assessment presently used during design are sufficiently robust, given the increasing diversity of applications in which composites are applied.

Once in service, a diversity of environments can be encountered in the chemical and process industries. These can cause damage to both matrix and the fibres. In some industry applications a corrosion resistant layer/barrier (or veil) containing more resistant fibres and gelcoat is commonly applied to the surface. Such layers are normally effective at preventing environmental damage but are relatively thin and can delaminate form the matrix leaving the structural wall vulnerable to degradation by the environment. There are particular issues for lined or painted glass fibre reinforced epoxy (GRE) vessels or pipework. If a lining is used then a compromise may be made on the resin and fibres used in the GRE vessel (less chemically resistant). It is important in this case to monitor the lining condition since lining failure could lead to degradation and failure of the GRE vessel in a shorter timescale than expected.

In-service inspection of non-metallic equipment is mainly visual and the effectiveness of the techniques used for assessing ageing deterioration is unclear, leading to a concern over the adequacy of in-service assessments presently conducted.

ELECTRICAL, CONTROL AND INSTRUMENTATION SYSTEMS AND EQUIPMENT

An analysis of MARS incidents where Electrical, Control and Instrumentation issues were a significant factor has been conducted. To summarise the analysis:

- EC&I issues were associated with 34 out of 348 accidents, i.e. 10%.
- 44% of EC&I issues were associated with Maintenance, 26% were associated with Design.
- 15% of the issues were associated with level detection, all associated with maintenance.
- Other significant issues include Loss of Site Power and Software failures, including problems with upgrading to new DCS.

These findings highlight the issues of old/obsolescent equipment when upgrading, repairing and maintaining instrumentation and control systems.

General observations from the EC&I accident data analysis are;

1. EC&I issues are a significant factor in around 2% of major accidents (RIDDOR 1%, MARS 10%, MHIDAS 2%).
2. EC&I accidents that could have been prevented by improved maintenance and testing represent a significant percentage of all accidents caused by EC&I issues (RIDDOR 60%, MARS 44%, MHIDAS 67%).
3. The biggest single factor in all EC&I failures is associated with Level Detection, often resulting in vessel overfill and loss of containment (RIDDOR 30%, MARS 15%, MHIDAS 20%). The vast majority of these failures are associated with inadequate maintenance and testing.
4. Design issues account for a significant proportion of EC&I associated failures (RIDDOR 33%, MARS 26%, MHIDAS 30%)–although these are not usually associated with ageing issues.
5. Other significant causes of EC&I failure include Loss of Site Power, Lightning/Earthing and Software failures, including examples of issues caused during upgrading to modern DCS control systems.

These findings show that suitable attention needs to be given to the potential ageing of safety critical EC&I equipment and systems, both in terms of equipment and systems physical and performance degradation and recognising and managing old/obsolescent equipment and systems, where challenges in terms of spares, repairs and competencies for modifying or checking older software and logic based systems may be presented. Experience has shown that particular care is needed when upgrading control and instrumentation systems to new digital standards where previously there has been a reliance on analogue equipment. Advice and guidance on the issues for EC&I management of change are provided in the Managing Ageing Plant-A Summary Guide, appended to RR823 (Horrocks et al., 2010).

SAFEGUARDS

Few descriptors in the databases give any details on what safeguards were meant to be present and which, if any, failed and why. As such the data cannot be relied on to provide a robust indication of the extent to which ineffective safeguards may contribute to major accidents, nor can it indicate the extent to which ageing may have contributed to the safeguard failures or shortcomings.

The number of potential safeguard 'ageing' related problems from the analyses of the MHIDAS and RIDDOR data are comparable; both data indicates that these represent approximately 0.4% of all events. This is low, and probably is a reflection of the reporting which tends to focus on the primary causes of the leak or incident rather than any secondary or contributory failures. The MARS data contains more comprehensive event descriptions, and this is reflected in the increased probability of age related safeguards issues in the data, of the order of 4% of all events. It is considered that the true figure could be significantly higher than this, as a high degree of under-reporting is likely in terms of the role of safeguard systems in these incidents.

The types of ageing related safeguards failures recorded include:

- Inoperable, blocked, jammed or passing isolation valves, including ESD/ROSOV valves
- Leaking bunds
- Cracked/leaking drains
- Poor condition earth bonding
- Faulty vent and pressure/vacuum relief valves
- Cooling water system failures
- Ineffective sprinkler and water deluge/spray systems
- Emergency generator that failed to start/delayed start on demand leading to power loss
- Failure/malfunction of fire water pumps to start on demand
- Inoperable site sirens/alarm
- Failure of monitoring/detection systems (these may be EC&I related)
- Failure of sump pumps to work on demand.

ANALYSIS OF THE UK OFFSHORE HYDROCARBON RELEASES DATA

This review examined the Offshore (OIR12) Hydrocarbon Releases (HCR) Database (HSE, 2008) as available from the online database. This is a detailed and comprehensive database of loss of containment incidents on Offshore Installations in the United Kingdom Continental Shelf. The database has been operating for over 15 years and reflects experience across a range of installations, many of which are old.

Although the offshore environment is different in some respects to onshore plant, in many cases similar processes are used and similar integrity management regimes are in place. The offshore industry has also been aware of the issue of ageing assets and various initiatives have been adopted to review and ensure the ongoing integrity of the processes and structures offshore.

An analysis of the frequency of leak events per unit of equipment population by cause (Table 4) shows that for most causes, the frequency of leaks is steady or falling. However, the data suggests that there may be an increase in the frequency of leaks caused by corrosion and mechanical fatigue and wear. Care must be taken in drawing hard conclusions from the data due to the relative simplicity of the cause classification in the reporting system, but the data may indicate that ageing may be increasing the probability of leaks/failures due to these mechanisms. It is also possible to speculate from the data that the frequency of leaks due to internal corrosion and mechanical fatigue/wear may be 'flattening off' over recent years as the issue of ageing has been brought into focus.

Table 4. Trends in the Frequency of Equipment Fault Causes in HCR Data

Causation Category		Average Events Per Annum in Period			Frequency Per Million Units of Population		
Cause Type	Specific Cause	1992–1998	1998–2003	2003–2008	1992–1998	1998–2003	2003–2008
Equipment Fault	Internal Corrosion	14.4	19.8	17.6	8.2	11.8	12.2
	External Corrosion	4.5	5.6	9.4	2.6	3.3	6.5
	Erosion	12.4	10.4	10.0	7.1	6.2	6.9
	Mechanical Failure	85.5	69.0	68.8	48.8	40.9	47.6
	Mechanical Fatigue	13.6	27.6	22.2	7.8	16.4	15.4
	Mechanical Wear	9.5	14.0	14.2	5.4	8.3	9.8
	Material Defect	9.6	6.2	4.8	5.5	3.7	3.3
	Specification Problem	0.0	2.2	0.8	0.0	1.3	0.6
	Manufacturing Problem	2.4	1.8	0.4	1.4	1.1	0.3

Overall, it should be noted that the 'age related' causes, i.e. corrosion, erosion, mechanical fatigue and wear only account for approximately 30% of all leak events in the database. Operational causes, procedural problems, design faults and other forms of equipment failures are identified as the main leak cause contributors.

It is understood that some additional text field information is available in the full HCR database which is not presented in the online version for public access. A review of this data may be worthwhile in the future to search for any additional insights into events that may have been caused by ageing mechanisms.

ADDRESSING AND MANAGING AGEING PLANT – LOOKING AHEAD

Previous work by HSE (Wintle, 2006) defined ageing and ageing plant as:

"*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 (usually, but not necessarily, associated with time in service) with an increasing likelihood of failure over the lifetime.*

Ageing equipment is equipment for which there is evidence or likelihood of significant deterioration and damage taking place since new, or for which there is insufficient information and knowledge available to know the extent to which this possibility exists.

The significance of deterioration and damage relates to the potential effect on the equipment's functionality, availability, reliability and safety. Just because an item of equipment is old does not necessarily mean that it is significantly deteriorating and damaged. All types of equipment can be susceptible to ageing mechanisms."

Although this definition was largely aimed at process containment, it does capture the essence of ageing and has been adopted by the HSE for its ageing plant initiatives.

Overall, ageing plant is plant which is, or may be, no longer considered fully fit for purpose due to age related deterioration in its integrity or functional performance. The review of the data for this study gave several anecdotal examples of where relatively new plant had suffered from advanced degradation by ageing mechanisms such as corrosion: ageing is not simply about old plant and equipment.

The reviews also show the importance of considering a wide definition of assets, not just focussing on the primary containment or the more obvious structures. The asset integrity programmes and consideration of ageing needs to include all SHE critical items, be these civil, structural, process, safeguards (prevention, control or mitigation measures) in nature. Given the specialist nature of EC&I elements, e.g. of safeguards systems, these are considered to merit specific attention.

The work has also highlighted the importance of identifying and managing obsolescent equipment, particularly older analogue control and instrumentation systems and equipment, as these can present significant challenges to maintain and also need careful management when moving to modern digital systems. The rapidly changing nature of modern C&I systems may mean that equipment becomes 'obsolete' after only a few years.

The findings of the data reviews reported here have been used to develop HSE's approach to ageing plant for onshore COMAH sites including the HSE's Ageing Plant Delivery Guide: Ageing plant is one of the COMAH Competent Authority's Strategic Topics and is currently being rolled out by HSE (HSE, 2011). HSE's initial approach to ageing plant has been to reconcile it with work carried out on integrity and maintenance management systems over the previous decade, building on this work to incorporate the broader impact of issues such as leadership identified by the work reported here. In addition, the findings of the work reported here provide insight and specific issues to help focus more detailed inspections and audits on ageing plant.

A similar approach is being adopted by the HSE for the offshore industry as part of the KP4 Ageing and life extension inspection programme (HSE, 2010).

The findings of the analysis, which included a review of European wide data, mean that these issues are also relevant across Europe and that ageing plant is likely to be an important topic for the oil& gas and process industries worldwide going forward.

As part of the study, a summary guide to ageing has been prepared to help managers and non specialist engineers understand ageing mechanisms and their management. This guide has been published by the HSE, attached to the back of RR823 (Horrocks et al., 2010) and provides a good way to promote awareness and understanding of ageing throughout the industry.

This study has not specifically addressed changes in codes and adequacy of design/construction – though the HSE expect duty holders to keep abreast of changes in codes and standards and assess the extent to which their facilities meet these.

The main focus of this study has been on how plant may degrade during its life, this encompasses the specific ageing mechanisms and obsolescence issues, but has also shown the need to encompass the change management regime, which can affect degradation mechanisms, obsolescence of equipment, and their management.

In summary, this study has shown that ageing mechanisms are a significant contributor to major accidents in the UK and across Europe. Guidance (Horrocks et al., 2010) has been developed for industry to raise awareness of this topic and a detailed delivery guide (HSE, 2011) is now being implemented by the Health & Safety Executive for COMAH sites with ageing plant being a key inspection activity: a similar approach is being adopted as part of the KP4 initiative for the UKCS offshore industry (HSE, 2010). The expectation is that assets should be being managed via an effective Asset Integrity Management system, which addresses the issues of ageing across all relevant asset types.

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