MANAGING FIRE AND EXPLOSION HAZARDS ON OFFSHORE AGEING INSTALLATIONS†

Tony Holmes[1], Stephen Connolly[2], Jill Wilday,[1,*] John Hare and Peter Walsh[1]
[1]Health and Safety Laboratory, Buxton, UK
[2]Offshore Division, Health and Safety Executive, Bootle, UK
*Corresponding author: jill.wilday@hsl.gov.uk

The subject of ageing installations is of considerable significance for the offshore industry and one that will remain so with an ever-increasing population of ageing installations. Ageing issues have also been highlighted by the Health and Safety Executive's (HSE's) recent Key Programme 3 (KP3) inspection programme on asset integrity. This paper will introduce new HSE guidance on managing ageing offshore installations and the consideration required for the five yearly Thorough Reviews of the offshore safety cases. Ageing issues include topsides equipment and structural deterioration, changes to the hazard profile of the platform, modifications, and improvements in knowledge and/or good practice. Situations requiring reappraisal of the fire and explosion risk assessment will be identified. More detailed examples will be given of the effects of ageing on the fire and explosion protection systems including fire and gas detection, active and passive fire protection, accommodation and temporary refuge (TR), heating, ventilation and air conditioning (HVAC) systems and building fabric integrity.

INTRODUCTION

Much of the offshore infrastructure has now reached, or exceeded, its intended design life, with many fixed installations over 25 years old. With the depletion of hydrocarbon reserves and the development of enhanced oil recovery technologies, it has become economically viable to operate installations beyond the period originally envisaged. Some platforms, though no longer producing from their own wells, have been modified and are used as production hubs, taking hydrocarbons from other wells and processing it for export by pipeline or tanker. The advent of carbon dioxide sequestration has also opened up the possibility of new uses for older installations and pipelines. Taken together, these factors have lead to an increasing requirement to extend the life of existing platforms.

Asset life extension raises important questions regarding the suitability of the infrastructure for continuing service, making it necessary to address the issue of ageing. It is useful to be mindful of what is meant by the term 'ageing' in this context:

> *Ageing is not about how old your equipment is; it's about what you know about its condition, and how that's changing over time.*
>
> [World Centre for Materials Joining Technology (TWI), 2006]

It is clear from the above definition that if the issue of ageing is to be properly understood, information is required about the installation.

KEY PROGRAMME 3 (KP3) –ASSET INTEGRITY

During the first few years of the 21st century, the Health and Safety Executive's Offshore Division became increasingly concerned about the apparent deterioration in the condition of offshore infrastructure. To investigate these concerns, a programme of inspections was launched, entitled Key Programme 3 (KP3) [HSE, 2007]. This involved the targeted inspection of some 100 installations, representing about 40 percent of the total.

KP3 recognised that the integrity of an installation depends upon the safety critical elements (SCEs). These are items the purpose of which is to prevent, control or mitigate major accident hazards, and the failure of these can cause or contribute to a major accident. KP3 focused particularly on inspecting the maintenance management of these SCEs, recording the inspection team's views on the general condition of the plant, and testing some SCEs. SCEs tested were:

- fire pumps;
- fire & gas detection;
- deluge systems;
- temporary refuge (TR) HVAC boundary dampers;
- pressure safety valves;
- riser emergency shutdown valves (ESDVs); and
- EX equipment (electrical equipment for use in explosive atmospheres).

Performance standards for SCEs play an important role in helping to ensure the safety of an installation. The Prevention of Fire Explosion & Emergency Response Regulations (PFEER) [HMSO, 2005] place a duty on operators to establish performance standards for SCEs. These standards are used to define the suitability of SCEs and act as a test for whether the condition and state of repair of SCEs remains sufficient. Guidance on PFEER performance standards is available [HSE, 1997].

The KP3 programme found that there were wide variations in performance across the offshore industry. Some of the main concerns identified were:

- the state of plant was often not fully understood;
- there was poor understanding of how degraded non-safety-critical plant could impact on the effectiveness of SCEs;
- the role of asset integrity in major hazard risk control was not fully understood;
- inadequate use was being made of integrity management data, and insufficient priority was afforded to ongoing maintenance; and
- the requirement to demonstrate performance of SCEs was not fully understood.

In more than 50 percent of the installations inspected the general state of plant was considered poor. Concern was expressed that some operators were not effectively addressing the deterioration in asset integrity that followed several years of underinvestment during periods of low oil prices (CRINE initiative[1]).

NEW GUIDANCE ON THE MANAGEMENT OF AGEING

HSE has recently issued new guidance to assist the offshore industry with the management of ageing assets [HSE, 2009]. This Information Sheet discusses how ageing can be managed for offshore installations, and provides information on the conducting of Thorough Reviews of the topsides integrity, including:

- fire and gas detection systems;
- corrosion of process vessels and pipework;
- active protection systems including Halon replacements;
- passive fire protection (PFP) and its monitoring systems;
- riser ESDVs; and
- accommodation and TR HVAC systems.

THOROUGH REVIEWS AND THE ASSESSMENT OF AGEING

The 2005 Offshore Installations Safety Case Regulations (SCR05) require the dutyholder to carry out a 5-yearly thorough review of the safety case for their installation [HMSO, 2005]. The objectives of the thorough review are to:

- confirm that the safety case, with any necessary updates, is still adequate, and is likely to remain so until the next thorough review;
- compare the case against current standards, HSE guidance (such as Assessment Principles for Offshore Safety Cases (APOSC) [HSE, 2006a], Guidance for the Topic Assessment of the Major Accident Hazard Aspects of Safety Cases (GASCET) [HSE, 2006b], offshore safety case guidance [HSE, 2006c]), industry practice for new installations, and relevant statutory provisions; to evaluate any deficiencies; and to identify and implement any reasonably practicable improvements to enhance safety;
- identify design parameters, ageing processes, changes in operating conditions and hence performance standards that may limit the life of the installation, or of its safety critical elements; and
- confirm that the safety case continues to demonstrate the effective identification, management and control of major accident hazard risks; and check that the management of safety is adequate, in particular that performance standards and key performance indicators (KPIs) remain relevant and effective.

[1]CRINE refers to an initiative to reduce capital and operating costs in the UK offshore oil and gas industry, and stands for 'Cost Reduction Initiative for the New Era'.

It should be made clear in the thorough review that the effects of ageing have been considered, and the summary submitted to HSE should provide brief details of:

- the ageing issues that have been considered in the review;
- any extended life assessment or revision to the major accident hazards (MAH) risk assessment;
- any changes to the management arrangements to take into account ageing; and
- the conclusions as to the impact on the case for safety.

EFFECTIVE MANAGEMENT OF AGEING

The effective management of ageing requires the understanding of a number of factors, and the application of a range of techniques to assess and manage the ageing situation. These are illustrated schematically in Figure 1.

The management of ageing safety critical elements is key to the overall management of ageing on an installation. The Energy Institute commissioned the World Centre for Materials Joining Technology (TWI) to produce a framework for the management of ageing SCEs using performance indicators. [The Energy Institute, 2009]. Key

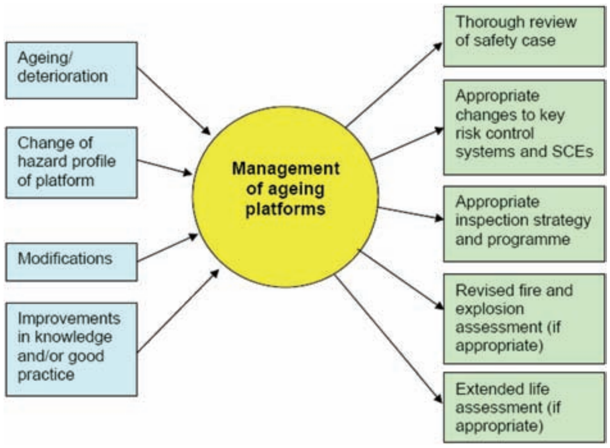

Figure 1. Schematic illustration of the management of ageing considerations

performance indicators are an important aspect of the Thorough Review's consideration of ageing, *see above*.

The change in hazard profile of the installation over time is an important factor to consider when assessing the continuing integrity of the asset; a primary determinant of the hazard profile being the changes in reservoir characteristics. These generally change over the lifetime of an installation, and require changes to be made to the process conditions on the installation. In most cases, the reservoir pressure will drop and, at some point, a form of enhanced oil or gas recovery will be needed, perhaps requiring compression. The gas/oil/water ratio may change possibly leading to more slug flow/vibration and there may be enhanced corrosion if H_2S levels rise.

Table 1 shows some indicators of ageing that have been identified [TWI, 2006], together with examples relevant to offshore installations [Dalzell, 2007].

Table 1. Deterioration aspects for offshore installations

Indicator of ageing	Examples relevant to offshore installations
External indicators of corrosion or deterioration	Paint blistering, rust streaks, evidence of corrosion at screwed joist or bolts, softening of PFP. Surface corrosion of blast walls may indicate that their structural response has been adversely affected.
External indications of incomplete reinstatement	Loose covers, ill fitting enclosures, loose bolts, missing equipment, incomplete systems.
Variations in standards	Modifications carried out to a higher standard such as double block and bleed or non screwed fittings while the original plant has earlier, lower standards.
Lack of commonality/incompatibility	Replacement equipment of a later design or from an alternative supplier. Interface problems between modern and older control systems.
Deterioration in plant performance	Difficulty in achieving a seal in isolation and ESD valves; Deterioration in pump performance, lower flow rates in deluge systems due to blockage, loss of sensitivity of detectors. Bearings may heat up and form previously unrecognised ignition sources.
Deterioration in structural performance	Initiation and propagation of fatigue cracks in structural members.
Deterioration of uninspectable SCEs	For example foundations, ring stiffened and single sided joints.
Increasing congestion and lack of optimal layout	Location of new plant such as pig traps in non optimal locations because of the lack of available space. Use of outer walkways for laydown and siting of new equipment. This leads to increased overpressures, new potential failures and routes to escalation.
Breakdown and need for repair	Repeat breakdowns and need for repair suggests that the equipment ageing. It is good practice to establish the underlying reasons for breakdowns and repairs.
Increasing backlog of maintenance actions	An increase in the number of repairs that remain unresolved can be an indicator that ageing is taking place. As the maintenance backlog grows it can become increasingly difficult to get maintenance back on track.
Inspection results	Inspection results can indicate the actual equipment condition and any damage. Trends can be determined from repeat inspection data. Water deluge performance parameters may be tracked through trend analysis.
Increasing failure to meet minimum functionality and availability performance standards	Reduction in efficiency, in pumping capability (e.g. fire water pumps) or heat up rates can be due to factors such as product fouling or scaling. Engines may become difficult to start. The TR may fail to maintain a seal when tested with blower doors, or dampers may fail to close more often.
Instrumentation performance	Lack of consistency in the behaviour of detection and process instrumentation can suggest process instability and may indicate that the equipment has deteriorated. It could also indicate a fault with the instrumentation, e.g. Pellistor gas detector set points tend to drift more with age. Process instrumentation may become less reliable in the presence of increasing water and sand.
Experience of ageing of similar equipment	Unless active measures have been used to prevent ageing of similar plant, it will be likely that the same problems can occur again. Particularly on vessels, PFP is known to delaminate with age and structural movement.
Repairs and plant outage.	May indicate that ageing problems are already occurring. Also a risk factor since if repairs have been needed during the life of the plant/structure, the integrity and necessity of the repair will indicate the potential for further problems, e.g. water deluge ring mains have 'temporary' repair clamps to mitigate through wall pitting corrosion. Records for availability may show that SCEs are having a greater downtime.

Modifications take place as the operating requirements of an installation change, for example changing the use to a hub for the import, processing and export of hydrocarbons from nearby platforms. Alterations to the topside equipment can result in changes to the loads on the platform structure, as well as changes to its MAH profile.

Advances in knowledge result in practices and apparatus that were once considered state of the art falling behind the standards of currently accepted good practice. For example, there have been developments in the understanding and techniques for explosion modelling, leading to higher predicted overpressures than was known during the design of many installations. This issue has recently gained prominence onshore following the Buncefield incident and subsequent investigation. [Buncefield Major Incident Investigation Board, 2008]. Similarly, advances have been made in our understanding of modelling for certain types of fire and of the effectiveness of deluge mitigation, that can be beneficial to the platform hazard profile.

There have also been developments in structural assessment, particularly for system strength, improved understanding of system performance following single and multiple member failure, and the effects on fatigue life due to load redistribution.

Technology developments include improved gas and fire detection, active fire protection systems including foam and dual systems, and passive fire protection systems. Improvements good practice are discussed in Oil & Gas UK management guidance [UKOOA, 2003].

INSTALLATION LIFE EXTENSION ISSUES

Extending the life of an offshore asset beyond the original design life requires particular attention to the effects of ageing. Several issues relating to hazard management become pertinent when the life of an asset is to be extended, including:

- the need for specific demonstration of fitness for purpose beyond the original design life of the structure and of equipment;
- design and operational issues relating to integration of new plant, processes or materials with old;
- effect of new fire and explosion scenarios from new plant etc. on existing mitigation systems, HVAC, fire and gas detection, active and passive fire protection systems;
- inspection and repair of passive fire protection and provision of integrity insurance for ageing piping/structure/equipment;
- degradation of emergency equipment and facilities;
- equipment obsolescence leading to substitution, modification or plant outage; and
- the effects of changes resulting from ageing on the installation's risk assessment, particularly that related to fire and explosion hazards;
- increases and decreases in operational loads and their effect on structural safety and foundation failure;
- understanding of degradation processes and its effect of reducing factors of safety;
- the need for detailed knowledge of the current state of the structure; and
- the need for better understanding of the structural response in the aged condition.

The ISO 1990x suite of standards for offshore structures introduce the need for specific demonstration of fitness for purpose when extending the life of an asset beyond the original design life. [International Standards Organisation, 2002-10].

DETAILED EXAMPLES ON AGEING

The preceding section has discussed the assessment of ageing in generic terms. Some specific aspects are outlined in more detail below: Further detail on the systems discussed is available [Dalzell, 2007].

GAS AND FIRE DETECTION

The detection systems installed on offshore installations need to be reassessed to ensure that they continue to function effectively. Changes to operating plant and processes may require revised approaches to gas and fire detection, such as a review of the spacing and location of detectors. Detectors themselves age, their performance degrades and they become obsolete compared with the latest models. Catalytic detectors for flammable substances are prone to poisoning. New knowledge and technologies can bring benefits e.g. acoustic detectors are independent of wind movement and when used in conjunction with infra-red (IR) beam instruments can increase significantly the effectiveness of detection systems, self-checking on IR point detectors increases reliability.

The technology of fire detection has moved on since the first installations were commissioned in the North Sea. Older equipment tends to require more checking, maintenance, and calibration activities. Some optical detectors are prone to blinding, either by hydrocarbon films, light from flares, sunlight, fog, or water on the optics. These problems, though not necessarily eliminated, are reduced with newer models of detector.

Changes to process conditions, the effects of degradation, and changes in knowledge combine to potentially compromise the efficacy of older detectors: these factors are summarised in Table 2.

Given the safety critical nature of these items of equipment it is prudent for operators to take the opportunity to review the detector arrangements on the installation as part of the thorough review.

PASSIVE FIRE PROTECTION

Cladding and coating materials are used to reduce the rate of heat transmission to vulnerable substrates. The selection of these passive fire protection (PFP) systems depends upon the objects being protected and the types of fire that the object might plausibly be exposed to. The PFP applied to the earliest North Sea installations was designed to protect

Table 2. Ageing issues with gas and fire detectors

Deterioration issues	Relevant changes in process conditions and modifications	Advances in knowledge, technology and good practice
Corrosion of detectors, cable trays, enclosures, electrical bonding points	Modifications may impact detector positioning	Older detection systems, particularly those using some types of catalytic detector, cannot achieve the performance of modern systems (e.g. acoustic, infra-red, open beam, combination with closed-circuit television [CCTV])
Drift in detector response		
Poisoning of catalytic sensors		
Blockage of sintered metal screen in catalytic sensors		
Open path detectors blocked by obstructions such as scaffolding		
Obsolescence leading to non-availability of like-for-like spare parts and lack of vendor support		
Old application programs may be incompatible with current hardware		

against burning of cellulosic materials, rather than hydrocarbons.

Since the first platforms opened offshore, our understanding of both fires and fire protection has moved on. In particular, there have been significant advances in the material sciences over this period, leading to the development of new types of PFP. A good review of PFP material types, applications and issues is available [Dalzell, 2007].

Ageing is a significant concern with PFP, the primary issues being degradation due to weathering and advances in technology since earlier installations came online. Table 3 summarises ageing issues with PFP.

Work has been undertaken by a number of researchers to establish the effects of weathering on PFP, especially with regards to its continuing efficacy [Kerr, 2006; Willoughby, 1998a, b, 2006a, b; Thurlbeck, 2006]. The findings of these studies are discussed further by Dalzell [Dalzell,

Table 3. Ageing issues with PFP

Deterioration issues	Relevant changes in process conditions and modifications	Advances in knowledge, technology and good practice
PFP often provided with no design safety factor	Changes in process conditions may reduce severity of fires	Better understanding of fire types, heat flux and duration
Poor application leading to disbonding from the protected structure	Modification to PFP requires matching materials and suitable procedures	Better understanding of critical temperatures/failure criteria for pressure vessels
Weathering		Old A60 standard for fire protection (60 minute barrier against flame and heat passage, and 60 minute temperature insulation, against cellulosic fires) inadequate for hydrocarbon fires
Damage		New standard for PFP for jet fires
Cracking of edge features		Better understanding of fire resistance of damaged and weathered PFP
Ingress of water e.g. to penetration seals or failure of topcoat		Better procedures for repair of PFP
Corrosion of substrate		Issues with blast resistance, use with deluge and application to hot or cold surfaces
Poor fire resistance of joint between old and new PFP unless suitable procedures adopted		

2007]. Criteria that require urgent repair of damaged PFP are identified as:

- cracks larger than 3 mm;
- more than 1 m^2 of disbondment;
- area >3000 mm^2 with damaged reinforcement;
- incorrectly located reinforcement; and
- area >3000 mm^2 below the minimum thickness specification

HSE has issued guidance on acceptance criteria for damaged PFP [HSE, 2007a].

Changes to the possible fire scenarios that could affect a platform will lead to a requirement to review the provision of PFP. Such a review might conclude that the original PFP provision is adequate, or that the PFP can be justifiably re-rated. In some instances replacement or repair might be required: in an offshore environment this is not a trivial task, and must be carefully managed. It might be that the re-evaluation of PFP requirements concludes that PFP is no longer required: in these circumstances it is preferable to remove the coating to reduce the risk of accelerated corrosion of the substrate by trapped water.

ACTIVE FIRE PROTECTION

The primary active fire protection systems installed on offshore installations rely on water sprays/foaming agents. As with the other safety critical elements discussed so far, our understanding of fire relief has changed since the first rigs were constructed. In particular, early standards for active fire protection did not fully account for all the factors pertinent to effective fire extinguishment [Dalzell, 2007]. The results of studies into the effective use of deluge systems to mitigate fires have been reviewed and made available by UK Oil and Gas [UKOOA, 2006].

Active fire protection systems are also particularly prone to physical ageing, such as corrosion of nozzles leading to blockage. It is vitally important, therefore, that adequate inspection, testing and maintenance of deluge systems is in place. Since the phasing out of halon systems electrical switchrooms, engine spaces, and gas turbines/enclosures now use water mist or CO_2 systems. CO_2 systems require changes in occupany, warning of use and revised escape procedures. Table 4 highlights some other ageing issues with active fire protection.

As with PFP, changes to use on the installation might lead to differences in the types and intensities of fires that can potentially be experienced. A review of the suitability of the active fire protection system should be undertaken, and needs to include consideration of the capacity of the fire pumps.

HVAC (HEATING, VENTILATION, AND AIR CONDITIONING)

HVAC systems are vital in providing appropriate atmospheres for the health of personnel, maintaining breathable atmospheres in refuge areas, providing ventilation to disperse flammable atmospheres, and maintaining a viable atmosphere for the operation of equipment called upon during emergencies [Dalzell, 2007]. It must be recognised, therefore, that HVAC systems are safety critical elements [HSE, 2006d].

Unlike the other SCEs discussed in this section, the requirements of standards for HVAC systems have not moved on greatly since the offshore industry was established in the UK. The primary ageing issues with HVAC systems relate to physical deterioration and to the possibility that air intakes are no longer appropriately located due to modifications of plant. Table 5 summarises the ageing issues associated with HVAC.

As with active fire protection systems, appropriate inspection, testing and maintenance regimes are required to ensure the ongoing integrity of HVAC apparatus.

Table 4. Ageing issues with active fire protection

Deterioration issues	Relevant changes in process conditions and modifications	Advances in knowledge, technology and good practice
Deluge systems may suffer degradation and nozzle blockage due to corrosion	Changes in process conditions may reduce severity of fires and increase effectiveness of deluge	Protection against jet fires excluded in ISO 13702 but included in early standards
Older systems may not be compatible with current standards	Modifications may obstruct deluge and impact on coverage and effectiveness	Improved information on effectiveness and application rates for different types of fire
Vulnerability to explosion damage		Better understanding of nozzle configuration for good coverage
Leaks in air trigger systems		Foam and dual systems available
Wear and tear of pumps and valves		New information on deluge mitigation of explosions
Obsolete components		
Deterioration/dilution of foam concentrate		

Table 5. Ageing issues with HVAC systems

Deterioration issues	Relevant changes in process conditions and modifications	Advances in knowledge, technology and good practice
LEV deterioration	Modifications will affect air flow patterns	New guidance on fire damper testing regime
Corrosion	Modifications to ductwork may leave it out of balance	Improved understanding of location of air intakes (in non-hazardous areas)
Deterioration of fan performance		
Contamination of ductwork with grease, mould etc.		
Deposition in ductwork		
Deterioration of TR sealing: doors, penetrations, panel joints etc.		
HVAC damper shutdown deterioration		

CONCLUSIONS

The foregoing discussion has highlighted the need to consider ageing of offshore installations. As the installed facilities become older, current good practice increasingly diverges from that prevailing at the time of commission. Changes in operational requirements lead to alterations in processes and plant layout, and the effect of these needs to be considered. Safety critical elements are crucial to the safe operation of offshore facilities, and the ageing of these elements in particular must be carefully assessed.

The thorough review process requires ageing to be taken into account, as it must also be when contemplating asset life extensions. The latest HSE guidance to assist operators with thorough reviews and ageing issues has been introduced [HSE, 2009], and some of the issues have been discussed in detail.

Recent returns to lower oil prices might increase financial pressure on already ageing installations. In this light, operators and regulators alike must remain ever vigilant to the threats posed by ageing in order to ensure safe operation in the offshore sector.

REFERENCES

Buncefield Major Incident Investigation Board, 2008. *The Buncefield Incident 11 December 2005 – the final report of the major incident investigation board, volume 1, appendix 4.* Kew: The Office of Public Sector Information.

Dalzell, G., Roberts, T.A., Jagger, S. Walsh, P., 2007. Guidance on fire and explosion hazards associated with ageing offshore installations, [Internal report] HSL report PS/07/06. Buxton: Health and Safety Laboratory.

The Energy Institute. *A framework for managing ageing safety critical elements using performance indicators*, 2009. In press.

HMSO, 1995. *The Offshore Installations (Prevention of Fire and Explosions, and Emergency Response) Regulations 1995.* SI 1995 no. 743. London: HMSO. [Online]. Available at: http://www.opsi.gov.uk/si/si1995/Uksi_19950743_en_2.htm (Accessed 3 April 2009).

HMSO, 2005. *The offshore installations (safety case) regulations 2005.* SI 2005 no. 3117. London: HMSO. [Online]. Available at: http://www.opsi.gov.uk/si/si2005/20053117.htm (Accessed 11 March 2009).

HSE, 1997. *Prevention of fire and explosions, and emergency response on offshore installations: approved code of practice and guidance*, 1997. 2nd Ed. London: HSE.

HSE, 2006a. HSE. *Assessment principles for offshore safety cases*, 2006. London: HSE. [Online]. Available at http://www.hse.gov.uk/offshore/aposc190306.pdf (Accessed 11 March 2009).

HSE, 2006b. HSE. *Guidance for the topic assessment of the major accident hazard aspects of safety cases*, 2006. London: HSE. [Online]. Available at: http://www.hse.gov.uk/offshore/gascet/gascet.pdf (Accessed 11 March 2009).

HSE, 2006c. HSE. *Offshore installations (safety case) regulations 2005, regulation 12 – demonstrating compliance with relevant statutory provisions*, 2006. HSE Offshore information sheet no. 2/2006. London: HSE. [Online]. Available at: http://www.hse.gov.uk/offshore/is2-2006.pdf (Accessed 11 March 2009).

HSE, 2006d. HSE. *Testing regime for offshore TR-HVAC fire dampers and TR pressurisation requirements*, 2006. HSE Offshore information sheet no. 1/2006. London: HSE. [Online]. Available at: http://www.hse.gov.uk/offshore/trhvac.pdf (Accessed 2 April 2009).

HSE, 2007. *Key Programme 3 Asset Integrity Programme: a report by the Offshore Division of HSE's Hazardous Installations Directorate*, 2007. London: HSE. [Online]. Available at: http://www.hse.gov.uk/offshore/kp3.pdf (Accessed 10 March 2009).

HSE, 2007a. HSE. *Advice on acceptance criteria for damaged passive fire protection (PFP) coatings*. HSE offshore information sheet no. 12/2007. London: HSE. [Online]. Available at: http://www.hse.gov.uk/offshore/infosheets/is12-2007.pdf (Accessed 13 March 2009).

HSE, 2009. *Guidance of management of ageing and thorough reviews of ageing installations*, 2009. Offshore Information Sheet No. 4/2009. London: HSE. [Online]. Available at: http://www.hse.gov.uk/offshore/infosheets/is4-2009.pdf (Accessed 7 April 2009).

International Standards Organisation (2002-10), Petroleum & Natural Gas Industries 19900 General Requirements; 19901-1 Metocean; 19901-2 Seismic; 19901-4 Foundations; 19901-3 Topsides; 19901-5 Weight Engineering; 19901-6 Marine Operations; 19901-7 Station Keeping; 19902 Fixed Steel; 19903 Fixed Concrete; 19904-1 Floating MSS; 19905-1/2 Jack Ups to be pub May 2010, BS EN ISO19900:200X.

Kerr, D.C., Willoughby, D.B., Kay, J., 2006. Criticality of damage and repair of passive fire protection (PFP) coatings: HSL cementitious PFP trials, [Internal report] HSL report PS/06/14. Buxton: Health and Safety Laboratory.

Thurlbeck, S., 2006. Acceptance criteria for damaged passive fire protection coatings. MMI Engineering Ltd., Report No. MMU013-P2-R-01.

TWI, et al., 2006. *Plant ageing management of equipment containing hazardous fluids or pressure*, 2006. (HSE RR509) London: HSE. [Online]. Available at: http://www.hse.gov.uk/research/rrpdf/rr509.pdf (Accessed 11 March 2009).

UKOOA, 2003. *Fire and explosion guidance part 0: fire and explosion hazard management, issue 2*, 2003.

UKOOA, 2006. *Fire and explosion guidance part 2: avoidance and mitigation of fires*, 2006.

Willoughby, D.W., Becket, H., Roberts, T.A., 1998a. Fire tests on specimens from the Bravo accommodation module for the Offshore Safety Division, [Internal report] HSL report PS/98/04. Buxton: Health and Safety Laboratory.

Willoughby, D.W., Becket, H., Roberts, T.A., 1998b. Fire tests on specimens from the Cormorant-Alpha accommodation module for the Offshore Safety Division, [Internal report] HSL report PS/98/05. Buxton: Health and Safety Laboratory.

Willoughby, D.B., Kerr, D., Royle, M., Kay, J., 2006a. Criticality of damage and repair of passive fire protection (PFP) coatings: HSL intumescent PFP trials, [Internal report] HSL report PS/06/15. Buxton: Health and Safety Laboratory.

Willoughby, D.B., Kerr, D., Royle, M., Kay, J., 2006b. Criticality of damage and repair of passive fire protection (PFP) coatings: HSL trials on specimens with repairs, [Internal report] HSL report PS/06/16. Buxton: Health and Safety Laboratory.