Process Safety in the Fertilizer Industry, a New Focus

Technical process safety came to prominence as a discipline in the 1960s and 1970s and has continued to develop since then. However, major process incidents continue to occur and it is by no means certain that the process industries’ performance is improving. The investigations into the explosion and fires at BP’s Texas City Refinery in 2005 have presented a new challenge to the process industries as a whole to re-emphasis and improve process safety management, and this has also been embraced by many regulatory agencies. This will set the tone for the years to come, particularly in terms of the role of leadership and the development of strong process safety cultures. Models are emerging to describe leadership behaviours and the characteristics of process safety cultures and more work is likely to follow. This paper describes the evolution of technical process safety, the new challenges that it faces to re-focus, the development of the concepts of process safety leadership and culture and the practical steps some organisations are taking to increase the profile of process safety.

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There is particular reference to the ammonia industry as at the same time process safety was being developed as a discipline in the 1960’s and 1970’s new production technologies were also being developed. Through the years there has been tremendous sharing of incidents and safety matters, however incidents continue to occur.

Fertiliser production and process risks
Manufactured fertilizers are essential for the production of adequate quantities of food, feed, fibre and bio-energy. However, the production of fertilizer products present challenges with respect to process safety due to the hazards inherent in the manufacturing processes.
The most common fertilizers in large scale manufacture are urea and ammonium nitrate, both containing ammonia synthesised using a process based on the Haber Bosch method discovered in 1909. It remains the only chemical breakthrough recognized by two Nobel prizes for chemistry, awarded to Fritz Haber in 1918 and Carl Bosch in 1931.

In the process, ammonia is produced from water, air, and energy; the energy source is usually natural gas. Steam reforming of natural gas is the most efficient route and is used in the majority of ammonia plants. These normally follow a conventional steam reforming single stream process, although production based on coal gasification is on the increase, especially in China. Economies of scale have led to increasingly larger plants being built; however the core technology of the single stream ammonia plants developed in the 1960’s remains economic for many operators, meaning many of the early plants are still operating.

The equipment and machinery used in modern large fertilizer plants can achieve high reliabilities with on-stream factors in excess of 90%. However, due to complex demands in terms of the compositions, pressures and temperatures present there remains an underlying significant process safety challenge, as demonstrated by numerous serious incidents that continue to occur and are reported in the news globally (Pattabathula, 2010).

In the most common large fertilizer production units the following hazards are identified as risks for which effective preventive measures need to be installed and maintained in a highly reliability state.

Industry incidents reported in recent media news (Sept 2009 to Sept 2010)
Ammonia Production

- Fire/explosion hazard due to:
  - leaks from the hydrocarbon feed system;
  - leaks of synthesis gas in the CO/removal/synthesis gas compression areas (75% hydrogen);
  - the formation of a flammable gas mixture inside equipment, for example in the reformer or process air line.

- Toxic hazards from:
  - the release of liquid ammonia from the synthesis loop;
  - accidental release during storage and handling;

Urea Production

- Equipment/piping failure due to corrosion;
- Explosion hazard due to the formation of a flammable atmosphere;
- Toxic hazard due to ammonia release;

Nitric Acid/Ammonium Nitrate Production

- Equipment piping failure due to corrosion,
- Explosion of the air ammonia mixture,
- Explosion of nitrite/nitrate salts.

Process safety incidents in fertiliser production

Historical reports of events show that the major incidents and accidents in ammonia plants are explosions and fires. The following review of published incidents demonstrates how process safety lessons continue to be re-learned.

Natural Gas Explosions in Furnaces

Case 1 - A primary reformer radiant box explosion occurred in January 1984 at the Western Cooperative Fertilizers Ltd Plant, Calgary, Canada (Sparrow, 1985) as the reformer was being lit for the third time. Severe damage to the furnace roof occurred, but there were no injuries to personnel.

Case 2 – A primary reformer explosion occurred in August 1985 on the auxiliary boiler at Triad Chemical Co, Donaldsonville, Louisiana (Davis, 1986). The explosion occurred during starting up; again no-one was injured but the primary reformer and adjacent equipment were heavily damaged. The investigation concluded that gas had entered through 16 small leaks on some of the block valves used on the tunnel burners, arch burners and superheater. After other auxiliary boiler fire box explosions in the USA, double-block-and-bleed systems have been implemented.

Case 3 – After a scheduled shutdown in October 1997 at Mossgas Ltd, Mossel Bay, South Africa, a powerful explosion occurred in the firebox of the primary reformer (Wet, 1998). Extensive damage due to the failure required the total rebuilding of the primary reformer. Two operators who were on top of the reformer escaped serious injury and suffered only minor cuts and bruises.

Case 4 – An explosion occurred at Petrokemija Kutina Fertilizer Co, Croatia (Babic, 2003) as the ammonia plant was being started up in May 2002 after a short shutdown. The walls of the reformer convection section and auxiliary boiler were damaged; nobody was injured. The investigation found that although some gas isolation valves were found to be leaking, the leak size was considered too small to create an explosive mixture so it was concluded that manual valves had not been sufficient closed. The lack of detailed instructions for lighting the boiler and
the lack of procedural control, as well as human factors, were cited as reasons for the explosion.

**Case 5** – An explosion occurred at DSM, Geleen, Netherlands (Duisters, 2005) in April 2003 during the lighting of a gas fired furnace of the melamine plant, resulting in three fatalities. The accident happened because of the incorrect application of a prescribed procedure for restarting the furnace after a brief shutdown. The investigation led to process hazards analysis studies on all DSM fertilisers gas fired equipment and many process safety improvements.

**Case 6** – An explosion occurred at Yara Tertre, Belgium (Flamme, 2010) during restart after an unplanned plant trip in July 2009. The accident resulted in two seriously injured operators and significant damage to the primary reformer, requiring a total rebuild. The incident investigation concluded that the direct cause of the accident was the introduction, by human error, of a large amount of fuel gas through unlit arch burner.

**Explosions in Process Air Feed line**

There have been a number of process air incidents relating to inadequate isolation or control when adding air into the process via the secondary reformer. This step is essential to add nitrogen to the ammonia process; however air contains oxygen which requires careful control.

**Case 1** - In a period of only seven months between May to December 1980, Columbia Nitrogen Corporation’s ammonia plant in Augusta, Georgia (Clarke, 1981) experienced a number of failures of the 14” process air piping due backflow of process gas from the secondary reformer, which ignited inside the piping when it came into contact with the hot process air stream.

The conclusions of the investigations were that the different failures resulted from a combination of factors such as (1) operators not following the prescribed operating procedures, (2) hardware in the form of a process air block valve and a separate check (non-return) valve both failing to stop the flow of process gas backwards and (3) the set point in the control system for the purge having been set in error.

After much hard-won experience the author concluded his paper with “While nothing can be made entirely failure proof, we have found that sound engineering judgement and experience can generally demonstrate room for improvement and often this can be accomplished without major expenditures if we look at what can go wrong. We proved that if it can go wrong it usually will!”

**Case 2** – At the Petronas Fertilizers, Kedah, Malaysia ammonia plant an explosion occurred September 1999 (Othman, 2002). The 12” process airline to the secondary reformer was ruptured for about 5-6 metres by the explosion, caused by back-flow of process gas containing hydrogen, methane and carbon monoxide into the process air line.

Contributory factors were stated as (1) inadequate knowledge of the operating procedures and (2) inadequate hardware specification for leakage class of trip valves.

**Explosions in Atmospheric Tanks**

Atmospheric pressure tanks containing an aqueous solution could be considered as less hazardous than other parts of plant; however the following two incidents show how they are an ever present danger.

**Case 1** – An explosion of a weak aqueous ammonia solution tank occurred in January 1973 at ICI Billingham, UK (Henderson, 1974). 1,000 tons of 10% ammonia solution escaped as the bund wall was demolished in the incident. As it
spread over the surrounding area, 4 people were affected by ammonia fumes.

It was concluded that the tank failed because of the combustion of gases in the vapour space of the tank. However, a source of ignition could not be identified and therefore a new Code of Practice was devised to cover all likely possibilities, including use of mandatory nitrogen gas blanket where hydrogen can accumulate, designing such tanks with the roof-to-wall weld such that it fails first in the event of over-pressuring and eliminating all possible sources of ignition. In particular, the tank should be fully earthed, and any associated electrical equipment should not be capable of initiating an explosion. The tank must be designed to eliminate the likelihood of static discharges.

Case 2 – An explosion occurred in October 2009 at Yara Ferrara, Italy (Schlaug, 2010) on an atmospheric aqueous ammonia storage tank collecting solution from purge scrubbers. The explosion was due to combustion of an air/hydrogen mixture, with the most likely scenario being that the explosive mixture ignited due to a lightning strike. Key learning from the investigation was that hydrogen/air could accumulate and reach explosive limits and this needs to be addressed through process design either by removing risk of explosive accumulation (e.g. nitrogen purge) or designing the systems so that all possible ignition sources are eliminated with the applicable hazardous area classification code.

**Toxic hazard due to Ammonia Release**

As well as fire and explosion hazards there is also the potential for toxic hazard due to the handling and storage of liquid ammonia. Appropriate precautions to protect both the operators and the local population need to be taken in the design and operation of the plants to ensure that reliability is maximized with minimum risk.

Case 1 - In July 1989 the casing of a high pressure ammonia pump on the Urea Plant operated by ICI Billingham, UK failed catastrophically without warning (Nightingale, 1990). The release of 10te liquid ammonia resulted in the deaths of two employees who were working close to the injector; other staff in local control room used portable breathing sets to escape as the control room proved to be inadequate as a toxic shelter.

Recommendations from the investigation included (1) formally registering machines (like vessels) so that inspection recording and design review of all repairs is completed.; (2) other similar equipment being examined with a view to how failure of the machine could lead to the possibility of loss of containment; (3) designing ammonia isolation system so that releases can be minimised so far as is reasonably practicable in the event of a loss of containment; (4) improving the integrity of the control room as a toxic refuge and (5) improving the site’s emergency procedures.

Case 2 – In May 2007 at Nagarjuna Fertilizers, India the seal of a high pressure ammonia pump failed after a cylinder locknut became undone (Raghavan, 2010), resulting in the release a large cloud of ammonia within the middle of an ammonia/urea complex. Despite the large release there were no reported injuries.

Recommendations included improving the design of the cylinder locknut and routine inspection of it as a critical component.

It was concluded that (1) additional isolation valves installed as a result of process hazards analysis helped greatly in providing quick positive isolation; (2) air respirator banks in all the main control rooms helped operators to continue and control the critical operations and (3) modifications should only be implemented with original equipment manufacturers consent.
Outside the ammonia and urea fertilizer production facilities the downstream ammonia storage facilities also continue to present a risk, where a "small" release can cause multiple injuries to members of the public.

Recently after an incident in which following an ammonia release resulted in over 100 members of the public seeking medical attention, U.S. Chemical Safety Board (CSB) Chairperson (Moure-Eraso, 2010) commented "We are seeing too many ammonia releases in our daily incident reviews. Though many are “small” releases, a high consequence accident that causes multiple injuries to members of the public is a serious one that warrants examination”. Based on the CSB's monitoring of media reports there were four high consequence incidents in the USA that involved the release of anhydrous ammonia which led to a total of six fatalities in 2009.

To ensure consistent company standards are applied at a number of their terminals which are of a different vintage, one company has recently described their approach using a process safety management-based assessment (Bridges, 2010).

The origins and development of process safety management

Technical process safety is by no means a new subject. Within the DuPont Company the tale is told of the company’s founder building his family home within range of his new explosives plant, on the banks of the Brandywine River in Delaware, as means to demonstrate his confidence in the safety of his new explosives process. That was in 1802.

In respect of the fertilizer industry a strong example of the long struggle for improvements in process safety was the founding of "Safety in Ammonia Plants and Related Facilities" meetings in 1956 by the American Institute of Chemical Engineers (AIChE) for the discussion of safety-related issues for ammonia plant operators. Initially the meetings were concerned only with air separation plants, which were susceptible to explosions and other incidents in those days.

Over the years, thanks not least to the useful role of the sharing best practices, the reliability of air separation plants improved steeply and the ammonia industry went through a phenomenal period of growth led by a revolution to modern production technology. The modern ammonia process was revolutionised in the mid-1960’s allowing single stream plants of approximately 1,000 tonnes per day capacity to be built based on steam technology since it has been developed to allow ever larger plants up to 3,300 te/day. However many of the older plants of 1960-1980’s vintage remain running. At the time they were built, plant designs complied with the regulations of that time. However in recent decades regulations have become stricter.

Beyond the fertilizer industry, technical process safety came to prominence in the 1960s and 70s as incidents such as Feyzin (1966) and Flixborough (1974) demonstrated the destructive power of high hazard processes. Techniques such as hazard and operability (HAZOP) study emerged to improve the ability to identify and control these process hazards; this technique was made public following the Flixborough disaster. The Seveso incident (1976) prompted the development of a European regulatory framework focused on major process hazards which emerged in the 1980s. In the meantime, in the USA the explosion at Phillips’ Pasadena, Texas site (1988) triggered the emergence of the first mandatory process safety management (PSM) system required by the Occupational Safety and Health Administration’s Process Safety Management Standard (1992) and the Environmental Protection Agency’s Risk Management Program (1996). Since then the requirements of the Seveso regime have been tightened; technical developments have been made in areas such as consequence modelling, quantified risk assessment and safety integrity
levels for instrumented protective systems; and the use of process safety management systems has become widespread and is considered industry best practice by International Fertilizer Association (IFA) Safety Handbook (2009)

BP Texas City and the Baker Report
One might expect that, by now, there would be a degree of confidence in the management of process safety across the process industries, together with clear indications of improvements in performance.

However that appears to be far from the case. This is shown in the history of incidents in ammonia production shown above, where similar process safety incidents continue to reoccur. Also in the wider petrochemical industry, process incidents have continued at roughly similar intervals to the past and one incident in particular – the explosion at BP’s Texas City Refinery on 23rd March 2005 – has presented a major new challenge to the process industries in terms of the focus on process safety management. The reason for this is that in its investigation report (US Chemical Safety and Hazard Investigation Board, 2007) the US Chemical Safety and Hazard Investigation Board (CSB) recommended that BP commission an independent review of process safety management across all five of its US refineries. The review (BP US Refineries Independent Safety Review Panel, 2007), often referred to as the Baker Report after its chairman ex-US Secretary of State James Baker, made a set of far-reaching recommendations to BP management that went well beyond the technical factors at which many major incident investigations stop. Moreover, the Baker Report suggested that these recommendations are likely to apply to many companies across the process industries. It is this challenge that has led to a renewed focus on process safety, enthusiastically embraced by regulatory authorities. So what is the nature of this challenge?

The Baker Report challenge
One fundamental finding within the Baker Report is that BP failed to sufficiently emphasise process safety. This in itself constitutes a significant challenge, but it also draws attention to the critical factor, which is that managing process safety and personal safety are fundamentally different activities (albeit overlapping). Indeed, the CSB investigation report was heavily critical of BP’s failure to learn the lessons from three major process safety incidents that occurred within a 10-day period at its Grangemouth Refinery in Scotland in 2000; an incident following which the UK Health and Safety Executive pointed out that “control of major accident hazards requires a specific focus on process safety above and beyond conventional safety management” (UK Health and Safety Executive (2003).

A second important challenge offered by the Baker Report relates to developing strong process safety leadership and process safety culture. Whilst the role of leadership and culture are well understood in relation to personal safety the Baker Report coins the terms specifically in relation to process safety, arguably for the first time. In doing so it again emphasises the differences between process safety and personal safety. This paper explores the linked concepts of process safety leadership and culture later.

Why the challenges have taken so long to emerge
In the meantime, it is useful to postulate why it has taken so long for these challenges to emerge.

Two factors may be important. The first is that process safety has evolved primarily as a technical discipline, hence the term technical process safety (or, in some companies, just technical safety). Its proponents and practitioners were largely engineers and, over time, company senior management came to trust and leave it to
the experts without gaining personal understanding or devoting prominent attention to it. Although the emergence of process safety management systems has brought the term management alongside that of process safety, these systems are based around the implementation of technical procedures such as change control and equipment integrity management. The emergence of the discipline of human factors has helped to bring focus on people within the process safety arena but has taken the Baker Panel to draw specific attention to process safety leadership and culture.

The second factor that may have held back the prominence of process safety is the revolution in personal safety management that has taken place since the early 1990s. The process industries have invested, and continue to invest, enormous resources in the reduction of personal injuries. The concepts of leadership and culture have long been associated with personal safety management, drawing on the models of traditional leaders in the field such as DuPont. Safety professionals have been very successful in training and coaching leaders and senior managers in the behaviours required to drive improvements in personal safety and, very importantly, bringing to prominence at board level safety performance statistics such as lost time injury frequency rates (which are also required by regulatory authorities). In many cases the focus on driving down injury rates (which are easily measured) may have diverted attention from process safety (which is not easily measured); this was clearly brought out in the CSB and Baker Reports. Worse, many senior managers and safety professionals may have come to assume that in improving personal safety performance they would also improve process safety performance. It has taken BP Texas City to point out that such an assumption has limited validity.

So two important factors may have combined to hold back developments in process safety; the assumption that it could be dealt with “behind the scenes” by the technical experts, and the primacy given to personal safety.

How other changes are making process safety management more difficult

In the meantime, the process industries have also been changing rapidly; new business practices have emerged that are making the successful management of process safety even more challenging. These include (Moosemiller and Antrobus (2009):

- The consolidation of small companies into larger ones, reducing the ability of central organisations to oversee individual sites;
- The decentralisation of corporate functions, forcing sites to set their own standards and resulting in a narrower experience base and loss of corporate memory;
- Reductions in work forces, stretching manpower and causing a loss of corporate memory, and;
- Frequent merging and demerging of companies, increasing the possibility of buying assets or operations with risk exposures that are not well understood.

All of these factors were present in the background to the BP Texas City incident.

And finally, while changes in business practices have the potential to make process safety management more challenging, the increasing age of many facilities and the extension of asset life beyond the original design intent has the potential to increase the likelihood of major process incidents, either due to failure to keep pace with increasing maintenance needs or due to failure modes that were not anticipated over the expected lifetime of the asset. Evidence from within the insurance industry has emerged that ageing assets may already be contributing to
increasing losses in the oil refining sector (Marsh Risk Consulting, 2003). This sector is unlikely to be alone.

All these factors combine to make a compelling case to take up the challenge of the Baker Report and focus increasing attention and resources on the management of process safety.

**Personal and process safety**

Before considering the challenges of developing process safety leadership and culture it is worth pausing to review some important differences between the management of personal safety and process safety and the implications of these differences.

- The relative rarity of process safety incidents compared to injuries within an organisation means that conventional lagging performance indicators are of little use. We cannot wait to learn from bad experiences. Proactive and predictive metrics that are specific to process safety are required.
- The relative complexity of causation of process safety incidents compared to injuries, combined with the fact that the agent of a process safety incident is often not the victim, means there is a need to influence the organisation as a team rather than as individuals. The focus must be on organisational practices rather than individual mindsets.
- The previous point is underlined by the fact that causes of process safety incidents and their effects can be separated in time by many years is an indication that un-revealed or latent failures can exist. When we return home uninjured each day we have immediate feedback that we have been successful in our efforts; however a design error or poorly executed modification may not reveal itself for many years; there is often no immediate feedback to enable recovery.
- The lack of personal experience of process safety incidents means that most learning must come from outside of the organisation.

These differences warn us against assuming that the “hearts and minds” approach to safety improvement, which works well when influencing personal behaviour to keep oneself safe and act as “brother’s keeper”, will be equally effective in securing improvements in process safety. It has a part to play, but avoiding process safety incidents involves the combined efforts of large numbers of people, many of whom will not be able to see the full picture from day to day.

This leads us to consider leadership and culture in relation to process safety.

**Process safety leadership**

Although aspects of the role of leadership in process safety management have been discussed in connection with incidents where the failures of senior management have been apparent, such as the Piper Alpha oil rig disaster of 1988 (Cullen, 1990), the emergence of models of required leadership behaviours have only emerged more recently, for example in the writings of Hopkins on the Esso Longford (1998) and BP Texas City incidents (Hopkins, 2009). Examples of required leadership behaviour include:

- Leading by example in terms of personal interest, communication and the setting of process safety goals.
- Ensuring that there is process safety expertise at levels of the organisation that are appropriate to the decisions that could affect process safety management, principally resource and investment decisions.
The operation of reward or incentive systems that give appropriate emphasis to process safety activities and goals.

- The investment of financial resources to undertake periodic process hazard reviews and - importantly - implement the risk reduction opportunities that they may identify.
- The investment in process safety training and competence assessment and the safeguarding of corporate memory, including retention of process safety expertise.
- The establishment of effective assurance or governance processes to provide assurance that process safety management systems are being implemented effectively across the organisation.
- The development of process safety performance indicators which provide performance information at different levels of the organisation that is appropriate to the types of resourcing and investment decision made at each level.
- The fostering of a strong process safety culture.

This leads to the concept of a process safety culture.

**Process safety culture**

The relevance of culture to process safety has been discussed by several authors (Reason, 1997 and Hopkins, 2005). These sources define a number of characteristics of organisations with a strong process safety culture. They are:

- **Cognisant** organisations that understand the nature of the process safety war as “a long guerrilla struggle with no final victory” [12].
- **Informed** (reporting) organisations that encourage the reporting of near miss events and are ever “mindful” of the impact of failure.
- **Just** organisations that exhibit a strong atmosphere of trust and understand that human errors are not the root causes of incidents but rather are caused themselves by personal, and organisational factors.
- **Disciplined** organisations that understand the importance of operational discipline, or everybody combining to perform every task right first time.
- **Learning** organisations that take the time and allocate resources to implementing lessons from failures in other organisation as well as their own.

**High reliability organisations**

The informed, “mindful” or resilient organisation is the subject of ongoing work on high reliability organisations (Weick and Sutcliffe, 2007). These are organisations that are complex, operate in environments where the consequences of failure are high and yet have better-safety performance than might be expected; examples are nuclear submarines, electricity grid controllers and air traffic controllers. Studies have defined five characteristics that distinguish these organisations’ behaviours in unexpected or fast-moving situations; behaviours that provide the resilience to prevent the development of serious incidents and return to normality.

- A preoccupation with failure - the recognition that weak signals of failure may be symptoms of bigger problems and demand a strong corrective response to prevent further degradation towards an incident. This would include errors that do not result in near-miss situations.
- A reluctance to simplify – a desire for detailed understanding of issues through the sharing of diverse opinions as opposed to the temptation to categorise issues by generic type.
Sensitivity to operations – paying close attention to what is actually happening; comparing what is happening to what was expected and interacting to build a clear picture of the real situation with a focus on front-line staff as the key players.

A commitment to resilience through the active development of the skills and knowledge or front-line to staff to handle unexpected situations.

Deferece to expertise – the capability to take a flexible response to an unexpected situation and allow the person or team best placed to respond to take authority.

This work provides an example of research that is aimed at developing blueprints for transforming organisations that will be increasingly valuable in the process industries. Other models and blueprints will emerge over time. In the meantime, what are organisations doing now to re-emphasise process safety?

Practical steps to improved process safety management

The efforts that different organisations are making to raise the profile of process safety and improve performance obviously differ according to the respective organisations’ perceptions of where they stand in terms of performance, management systems and culture as well as their aspirations. While there is no widely accepted blueprint for a transformational process, it is possible to identify a number of activities that various organisations are using to improve the management of process safety. Some of these are listed below:

- Promoting a shared understanding of process safety and process safety management at all levels of the organisation by means of training.
- Reassessing or updating the company’s process safety risk portfolio by means of structured hazard reviews and process hazards analysis revalidations with the involvement of front-line staff to increase the focus on human factors.
- Establishing process safety expertise in appropriate parts of the organisation to complement personal safety management resources, recognising that many safety managers are insufficiently trained or experienced to hold process safety management responsibilities.
- Undertaking assessments or audits of process safety management systems and the health of protective layers relating to key process hazards to establish baselines for improvement plans.
- Establishing process safety committees to promote process safety at senior and local operating levels.
- Developing process safety goals and metrics at site and higher levels to provide an appropriate focus on performance and demonstrate effective corporate governance.

Conclusion

In conclusion, the process industries have been presented with a challenge to improve the management of process safety as a result of the investigations into explosions and fires at BP’s Texas City Refinery in 2005. There are many examples of companies and industry organisations taking up this challenge and starting to embrace the concepts of leadership in process safety and process safety culture. These concepts will doubtless undergo further research in an effort to establish methodologies for transforming performance. But in the meantime, recognising culture change as a long-term aspiration, companies are taking steps towards raising the profile of process safety across their organisations and improving their understanding of process risks and their management systems.
References


Cullen (1990), The Public Inquiry into the Piper Alpha Disaster, HM Stationery Office.


Hopkins, A (2009), Failure to Learn – the BP Texas City Refinery Disaster, CCH Australia.

Hopkins, A (2005), Safety, Culture and Risk - The Organisational Causes of Disasters, Hopkins, CCH Australia.


UK Health and Safety Executive (2003), Major Incident Investigation Report, BP Grangemouth Scotland 29th May – 10th June 2000,


Weick and Sutcliffe (2007), Managing the Unexpected 2nd edition, Wiley.