Learning from emergency response in the process industries

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The purpose of emergency response is to prevent and reduce further damage to the operators of hazardous sites and the surrounding population. However, it is well known that there are many accidents in which the emergency response was deficient for various reasons. For example, the Texas City Disaster in 1947 left 500 fatalities and over 3500 injuries behind and destroyed neighbouring businesses and industrial sites. The West Fertilizer disaster of April 2013 in West, Texas, USA was among the most recent examples of an emergency response failure. Also, the Tianjin port fire and explosion in 2015 resulted in 165 fatalities, the majority of them firefighters, police officers and 55 civilians. However, not only the chemical industry experienced large losses during intervention activity, the grave consequences of the Chernobyl accident included the immediate deaths of 28 first responders and firefighters from acute radiation sickness in 1986. Furthermore, the earthquake and tsunami in Japan in 2011 also resulted in severe loss. The Buncefield accident in 2005 caused water pollution because the tertiary containment as the last line of defence, was insufficient to prevent the fire water run off during the emergency response activities.

The aim of the paper is to present cases where emergency response failed and provide key learning points for future improvement. The study also shows the common causes, contributing factors and potential lessons learned from these accidents. It even identifies critical areas where failure can drastically destabilize effective planning and execution of emergency response. Studying these failures can make a significant contribution to improving emergency preparedness and reducing severity of consequences resulting from a poor emergency response.

These findings could help operators of industrial sites in different sectors and the emergency response community all over the world to assess and recognize the strengths and weaknesses of their own preparedness and response plans. Implementing these lessons may contribute significantly in improving emergency preparedness and response.

Keywords: emergency response, preparedness, lessons learned, case studies

Introduction

To prepare for emergencies, operator of hazardous establishments need to draw an emergency response plan. However, it is well known that there are many accidents in which the emergency response turned to be inadequate and thus, mitigating the consequences of those events did not eventuate.

The main obligations to an operator of a chemical site relating to emergency response is defined by the Seveso III Directive (Directive). It also provides requirements relating to emergency planning in Article 12 and Annex IV. In addition to the Directive, the requirements of emergency planning have also been set out in many publications. For example, the UK Health and Safety Executive published its guidance document on Emergency Planning for Major Accidents in 1999 (HSE, 1999) and the Centre for Chemical Process Safety also issued Guidelines for Technical Planning for On-Site Emergencies that cover "the technical knowledge needed for proper planning end effective response to on-site emergencies" (CCPS, 1995). The U.S. Chemical Safety and Hazard Investigation Board (CSB, 2017) reviewed 14 investigation reports and published a study that identified deficiencies in emergency response and revealed recommendations relating to emergency response which can be applied in the analysis of major accidents.

Similar requirements were imposed within the nuclear industry. For example, the Nuclear Regulatory Commission revisited the role of emergency preparedness for protecting the public near nuclear power plants following the Three Mile Island accident in 1979. A joint publication was issued on emergency preparedness and response (US NRC and FEMA, 1980). Furthermore, the International Atomic Energy Agency (IAEA) also published safety related standards about Fundamental Safety Principles (IAEA, 2006) and Preparedness and Response for a Nuclear or Radiological Emergency requirements (IAEA, 2015).

The Organisation for Economic Co-operation and Development (OECD) has been playing a very important role in both the chemical and nuclear sector for many years. The OECD Working Group on Chemical Accidents (OECD WGCA) has over 25 years of history in supporting the activity of prevention of chemical accidents with valuable publications (OECD, 2003) and regular meetings. Likewise, the OECD Nuclear Energy Agency (OECD NEA) has a long tradition of expertise in the area of nuclear emergency policy, planning, preparedness and management. Through its technical programmes, they offer assistance in the nuclear preparedness field. They even help facilitate improvements in nuclear emergency preparedness strategies and nuclear emergency response at the international level.

The European Commission Joint Research Centre (EC JRC) has also conducted a thorough analysis on learning from emergency response. The report is expected to be published in 2018. Based on that research, the EC JRC contributed to both the OECD NEA and the OECD WGCA with the analysis of major chemical accidents. The OECD report on "Towards an All-Hazards Approach to Emergency Preparedness and Response: Lessons Learnt from Non-Nuclear Events" will most probably be published prior or after the Hazards conference.

This paper addresses the main questions of why emergency response can fail and which are the most common deficiencies during interventions. Furthermore, the objective is also to address common causes and the main learning points from the accidents analysed and recommendations in improving emergency preparedness and response in both the chemical and nuclear industries.

The study focuses on major accidents which occurred in fixed industrial facilities. The cases selected are from the public database of the European Commission's major accidents reporting system (eMARS, n.d.) the Analysis, Research and Information on Accidents (ARIA, n.d.) database operated by the French Bureau for Analysis of Industrial Risks and Pollutions (BARPI), the U.S. Chemical Safety and Hazard Investigation Board and the Japanese Failure Knowledge Database. The knowledge and experience gained from conducting the research for both the EC JRC and the OECD NEA reports was utilised by the author without repeating any parts of the reports which were not published at the time of the paper.

Methods

The cases were selected based on the accident descriptions and the consequences holding information about the emergency response. The criteria involved emergency response elements regarding evacuation and sheltering, in cases where members of the intervention team died or suffered injuries. It also looked at the effectiveness of onsite and offsite emergency response to protect the public. Among the accident reports pulled from the open sources and reviewed, four cases were further analysed and described in the paper below. Further, more detailed information on these cases are available in the official investigation reports. It is not the objective to provide the whole picture about these cases, the paper focuses solely on the aspects of emergency response. Finally, the conclusion highlights the main findings and key learning points.

Cases

Case 1 – Lack of evacuation

At 10.15 a.m. on the morning of 25th July 2013, a series of explosions occurred in the finished products storage area of a fireworks factory. The initial explosions - three subsequent blasts according to calls from members of the public to the fire service - presumably occurred in the vicinity of two sheds, which were used to store finished products. Observations of the effects indicate that the sheds probably exploded simultaneously. The explosion caused the death of three workers and the owner of the factory, as well as one firefighter. The accident caused extensive material damage inside and outside the establishment, including civilian buildings within a radius of up to 1 km.

Considering the dynamics of the accident, the effects, and the information provided by the firefighters involved in the emergency response, it is likely that the internal emergency plan was not activated, and the external emergency assistance was not adequately and quickly demanded by the company. Firefighters were called first only by the citizens of surrounding towns, after seeing and hearing explosions.

The call from the company was finally made after eight calls from citizens. Moreover, after the first explosions, the lack of evacuation of the surviving workers inside the plant led to more severe damages. It seems that the operator first failed to call the emergency services in time and detect the situation requiring the immediate evacuation of the site. The investigation revealed, that the presence of a second access route on the opposite side to the first access route would have facilitated the positioning of firefighting equipment and the emergency operation centre. That would significantly have reduced the firefighting team's risk of exposure to the shock wave and material debris during the operation (eMARS, n.d.).

Case 2 – Emergency responders affected

On 17 April of 2013, a fire and a massive subsequent explosion occurred at the West Fertilizer Company in West, Texas, USA. The blast caused 14 fatalities, of whom 12 were volunteer firefighters and two members of the public. The explosion completely destroyed the plant and damaged more than 150 buildings in the vicinity. Over 200 injuries were reported in the accident.

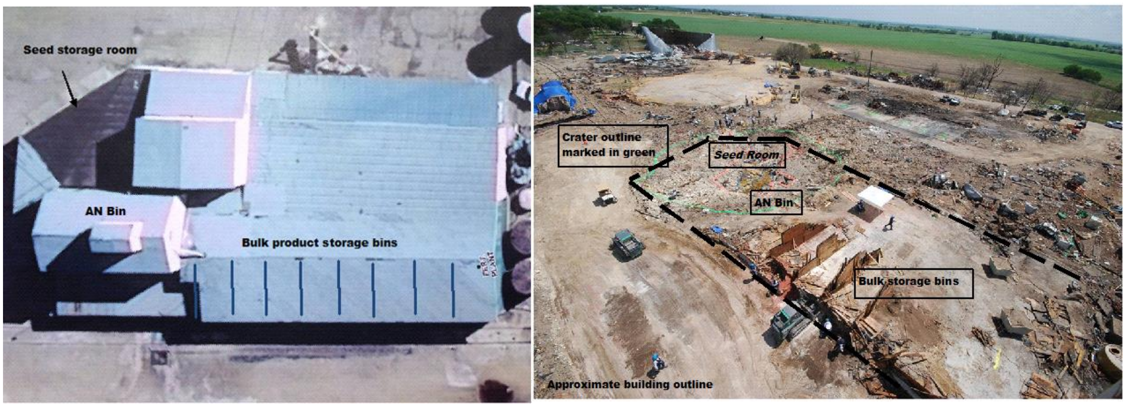

Figure 1: The storage area before and after the explosion (Photo Courtesy of Texas State Fire Marshal's Office)

West Fertilizer was a storage retail distribution facility. Its main activity included selling fertilizers, chemicals and grains to the public. Fertilizer was stored in wooden bins. At the time of the accident, 30-40 tons of fertilizer grade ammonium nitrate with a 34 percent total nitrogen content was stored in bulk granular form. On the evening of the accident, an emergency call from a citizen was the first report of the fire. Soon after the firefighters arrived and started to fight the fire, an explosion occurred.

Apparently, the volunteer firefighters were not informed of the explosion hazard of the fertilizer. Therefore, they did not have sufficient information to make an informed decision on how best to respond to the fire. In fact, there was a confusion about the safety features of the fertilizer; it was thought that it would not explode and that it was enough far away from the blaze to not concern the firefighters (White, D. 2014). The investigation revealed that firefighters did not receive adequate training on emergency response to storage sites that handle fertilizer grade ammonium nitrate.

Also, the CSB's investigation (CSB, 2016) found that lessons learned during emergency responses to ammonium nitrate fertilizer incidents – in which firefighters perished - had not been effectively disseminated to firefighters and emergency responders in other communities where ammonium nitrate is stored and utilized. There was no incident command system; unidentified firefighters were observed around the plant with a civilian; the emergency scene operation was conducted in an unstructured manner without adequate supervision (Texas State Fire Marshal's Office, 2013).

Case 3 – Spectators at the scene

Early in the morning on 16 April 1947 a small fire was spotted on the Grandcamp ship dock at Texas City, Texas, which carried ammonium nitrate fertilizer. The longshoremen lowered a fire hose to put out the fire with water but the captain ordered the ship's hatches to be shut to protect the cargo of ammonium nitrate from being destroyed by water. They tried to suffocate the flames by closing the hatches and ventilators and turned on the steam system. Soon after the compressed steam pressure blew off the covers of the hatches and flames erupted from the openings. At 9.12 a.m. a powerful explosion occurred (Fire Underwriters, n.d.).

Another ship, the High Flyer was tied up in the adjoining slip and it was loaded with sulphur and thousands of tonnes of ammonium nitrate fertilizer. It was pushed by the blast and collided against another cargo vessel and was damaged. An hour later smoke rose from the waterfront. Everyone left the ship but nobody considered the situation dramatic until late evening, following an unsuccessful attempt to pull the burning ship away from the docks. At 1.10 a.m. on 17 April the High Flyer also exploded. As a result of the two explosions, all fire fighters and numerous spectators were killed as were many employees in the neighbouring chemical facility. The accident caused the death of over 500 people and injured 3500. This was 25% of Texas City's population at the time. Also, serious damage was caused in the nearby refineries, ripping open pipes and tanks of flammable liquids and starting numerous fires (Stephens, Hugh W., 1997).

At the time of the disaster there were no restrictions on transportation of fertilizer. The Railway Terminal had not enquired about how to handle the shipment, but the vice president of the company later asserted that after he noticed that the fertilizer came from an army ordnance plant, he had asked a representative of the plant if the material was explosive. He was told it was not. Furthermore, no one considered the cargo of the High Flyer. It was stated that there was an "even chance" that the High Flyer would explode. The dock area was built-up with two large chemical plants, three large oil refineries, oil tank farms and a concentrated dock area for both general cargo and petroleum products. Therefore, they were contributors to the domino effect. There was also a significant delay in communicating with the volunteer fire department, as the telephone workers were on strike so the system was not available. Finally, the high death toll was caused by the fact that several hundred people were wandering around because they saw the "pretty gold, yellow" smoke and because "it was beautiful to see".

Texas City was a boomtown in those years and the priority appeared to be the economic growth over safety.

Case 4 – Fukushima Daiichi

On March 11, 2011, a magnitude-9 earthquake (Great East Japan Earthquake), shook north-eastern Japan, unleashing powerful tsunami waves that reached heights of up to 40.5 metres. It also triggered chemical and nuclear accidents. It hit several oil refineries and industrial complexes which caught fire and initiated a nuclear accident at the Fukushima Daiichi Nuclear Power Plant located 180 km away from the hypocentre of the earthquake. It was a Level 7, major accident event on the International Nuclear and Radiological Event Scale of the International Atomic Energy Agency (INES), similar to the Chernobyl accident in 1986. However, it is important to note that the release of radioactive material to the atmosphere from the Fukushima accident was less than 15% of the Chernobyl release.

Regarding the tsunami, the site's design-basis heights had been required based on historical records, which covered only 400 years. There was no counter-measures against tsunami with a recurrence period of 1,000 years or more, as was revealed by the investigation (IAEA, 2013).

The on-site emergency response was extremely difficult as most of the available resources had already been struck and destroyed by the earthquake and the subsequent tsunami. The complexity of this large-scale event challenged the remaining capabilities to tackle both the natural and the technological disaster. Consequently, the mitigatory measures could not be launched in a timely manner. The earthquake caused damage in the electrical power system that resulted in the loss of the cooling function at the operating reactor units. The tsunami also damaged multiple pieces of equipment in the plant.

Apparently, at the time of the accident there were no procedures for responding to a nuclear emergency and a natural disaster occurring simultaneously.

Another critical aspect was revealed by the IAEA, that "when many of the contractors left the Fukushima Daiichi site during and after the accident, the site employees were unable to carry out many of the contractors' responsibilities and lacked the experience or equipment to undertake key emergency mitigatory actions". Apparently, the employees were not responsible for, or trained in carrying out the contractors' tasks, which created an additional burden on top of their already extremely difficult job.

Common findings of the accidents analysed

Commonalities in the major accident reports analysed relating to emergency preparedness and response both in the chemical and nuclear sectors can be identified. The list is not exhaustive, further and more detailed information can be retrieved from the thorough analysis of the cases available in the sources indicated in the introduction. However, based on the four events demonstrated above, some similar contributing factors can be recognised, such as the followings:

- Lack of emergency response procedures with clear roles and responsibilities, both in the chemical and nuclear sectors.
- Lack of or inadequate training and emergency exercises; lack of training for emergency responders, including tasks assigned to contract workers.
- Lack of potential and relevant accident scenarios in the site's risk assessment due to their low probability.
- Lack of or late evacuation which caused additional threat to workers and the surrounding population.
- Lack of incident co-ordination centre caused a confusion about the necessary intervention or even the site's shutdown procedures. Positioning of the emergency operation centre also seemed inadequate which resulted in delayed actions and further injuries to firefighters.
- General deficiencies in emergency response procedures or the on-site and off-site emergency plans.
- Need to upgrade fire detection and/or extinguishing water system (ten cases). For example, better performance of the extinguishing system in terms of adequate water flow (delivery and capacity of the water supply) was highlighted in one case.
- Inadequate public warning systems which caused confusion. In one accident an independent alarm system was requested after the event because the cable of the system was ruined by the fire and the company could not use its own means. They needed to contact the off-site emergency response services to launch the alarm. Alarms can also cause confusion. In one case it confused the control room operator due to the phenomenon of alarm flooding.
- Deficiencies in communication between emergency services and lack of or late communication to the public. There was a case when the entire communication system with the fire brigade failed in the middle of the emergency response. As it was demonstrated above, there was a confusion about the potential hazard; it was clearly underestimated and caused additional casualties.
- Drainage system was insufficient and could not contain the fire water run-off which caused environmental damage (Hertfordshire Fire and Rescue Services, 2006).

Key learning points

Applying the knowledge gained from the analysis of the causes and contributing factors, a list of key learning points can be drawn up. These observations can be taken and developed further when producing an emergency response plan. The most common learning themes are derived from the reports are demonstrated below:

a) Develop emergency procedures and training for emergency situations in hazardous facilities. These procedures should consider all possible accident scenarios identified independent of their probability of occurrence. Based on these scenarios, resources and capabilities must be assessed and appropriate preparedness equipment must be on hand.

b) Roles and responsibilities of the various stakeholders need to be clearly defined and well communicated in the emergency procedures. Issues between the operating organization, the regulatory body, the government and the public had an impact on the emergency response to the accident. To ensure the effectiveness of well-defined roles and responsibilities, an integrated approach to training in emergency preparedness and response becomes critical.

c) Contractors working in the operating organization and their role in the event of an emergency should be understood. The roles and responsibilities of contractors in an emergency need to be well defined at the preparedness stage to allow for protection of the contractors, as appropriate.

d) Specific procedures should be in place for critical functions, such as power or process shutdown; remote shutdown facilities should be appointed.

e) Companies should set up good warning systems to ensure that everybody in the site and nearby facilities are informed about the emergency. Such systems should be tested regularly.

f) Emergency drills should be organised periodically to ensure that the staff with formal role in emergency response are familiar with their responsibilities. The overall aim of such drills is to check the adequacy of the emergency plan and fix problems afterwards. In addition to that, the off-site or external emergency plan should be tested regularly and updated based on the learning from drills.

g) Communication between the emergency responders and the public should be effectively facilitated and conducted in a timely manner to ensure that people are continuously updated on the situation. Protocols for the emergency operation centre to assist communication between the emergency teams and a media centre also should be set up.

h) Spectators can cause extra stress and work load for emergency services, therefore they should be kept away from the accident. It is essential since a secondary explosion or further toxic release are possible. For example, staff that are not involved in the emergency response activities should leave the scene and not trying to capture a video or photos of the accident (Lees, 2012).

i) There are situations when a fire becomes so immense, that it is best to move everyone back for their own safety and let the fire burn itself out.

j) In case of the possibility of natural hazards, the assessment of those threats needs to consider the potential for their occurrence in combination, either simultaneously or sequentially, and their combined effects on multiple units of a plant.

k) A single or dedicated emergency operation centre or command system should be established during the event. Its location should be carefully chosen with consideration given to the emergency situation, weather conditions, and the need for proper distance between the centre and other process areas of the establishment.

l) All necessary information about the site, such as a map illustrating the location of response equipment, emergency exits and assembly points should be available for emergency responders when they arrive at the scene.

m) Potential environmental impacts should be considered during emergency response and fire water containment should be able to prevent fire water run-off (Atkinson, G. 2017).

Conclusions

Emergency plans can fail and emergency response can be deficient. One of the main challenges in emergency response is to identify accident scenarios; it seems, that among credible scenarios planners should think also about scenarios with low probability of occurrence. After identifying those scenarios, necessary resources must be assessed in order to prepare for intervention in case of an emergency.

Training and emergency drills are equally important to have a successful emergency response both onsite and offsite. Right behaviour in case of an emergency situation, knowledge about what to do in case of evacuation or sheltering are crucial information must be shared with all involved parties. Assembly points/areas, safe havens, power supply, water supply, electricity, proper shutdown procedure, emergency operation centre with incident commander, media information centre, dealing with spectators, medical facilities and first aid areas, communication system both inside the establishment and to the public, communication point, cooperation between emergency response teams, forces according to the level of seriousness of the event. Response teams should have knowledge about the site and must be informed about the level of degradation and current situation on the circumstances and surrounding hazard sources. Emergency responders can die or be injured in major accidents, during or after the intervention takes place.

Severe technological accidents, either in the chemical, nuclear or other sectors can cause substantial fear and anxiety, even post-traumatic shock in populations. It is, however, necessary to focus on not only the negative but the positive examples where establishments had an operational emergency plan. It can ensure that operators are able to stop the escalation of the event and mitigate the consequences in time. It is therefore pertinent that decision-making rules and procedures are designed to make sure that emergency response is prompt and effective.

Emergency planning can be successful if all three elements of preparedness, response and recovery are considered from the start of the planning phase.

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