Learning from Incidents – A Personal Journey over Decades of Manufacturing Hazardous Substances

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The author spent 32 years primarily in the manufacturing of hazardous chemicals. These ranged from peroxides, ammonia, acids, ammonium nitrate and the full range of explosives and blasting accessories. The author was involved in several process safety incidents over this period. By using a selection of 6 of these the author will outline the nature of the incident, the causes and the lessons learnt at the time. The incidents to be described / analysed are:

- A runaway exothermic reaction involving hydrogen peroxide (1970)
- A dangerous start-up of a standby boiler feed pump for a waste heat boiler (1972)
- The hazardous entry into a mist precipitator to remove a star-wire which had shorted out (1973)
- Installation of an inline filter on an ammonium nitrate lien – unexpected explosion (1980)
- Modification on a nitro glycerine separator leading to a major explosion with 8 fatalities (1982)
- As Director, dealing with the aftermath of a major nitro glycerine explosion with 7 fatalities (1994)

The author will put them into the context of the period and environment in which they occurred (pre- Process Safety). The incidents will then be reviewed in terms of the modern thinking and practices of good process safety. Appropriate actions with today's knowledge and practices will be tabled. Lessons learnt at the time and in the modern context will be drawn out. Hopefully, these will be of value to others.

The period over which the incidents took place (late 60's to the end of the 90s) also saw the development of the fundamentals of process safety management although the terminology was loss prevention rather than process safety. The author will link the incidents to the state of play in process safety at the time. The author will illustrate the parallel between the development of process safety knowledge in industry to the growth in his personal development in the safety field. It will illustrate that both experience and continuous learning is required to understand process safety and be able to teach / influence others.

KEYWORDS: Learning from incidents, Major Hazards, Safety culture

Introduction

The author has spent most of his working life as a graduate chemical engineer in the manufacture of hazardous substances. The hazards have been inherent in the products made, raw materials used, and hazardous conditions encountered in the manufacturing processes. This period has spanned some 30 years (1968 – 1998) and includes a spell in the UK but mainly relates to managing production activities in South Africa. The industries covered include peroxide chemicals, acids, fertilizers and commercial explosives.

A number of significant process safety incidents occurred over this time where the author was directly involved or was closely linked to the events. Actions or decisions were made at the time related to each incident. Some of these were risky. With the benefit of hindsight, it can be seen why the action or decision was taken. With the advancing knowledge and experience of modern sophisticated process safety thinking and measures as they stand today, it is possible to review those situations and decisions and consider what the response today might be. It is also possible to consider the actions / decisions in light of the process safety climate at the time (both in the UK and in South Africa). The personal growth of the author in the field mirrors to an extent the ongoing development of process safety as a specific discipline.

By analysing 6 events, the author will distil learning points as seen at the time and now, by looking back, using modern thinking on process safety. It is hoped that readers will gain insight into why these incidents happened and how they may be approached today.

There is an element of recklessness in some of the incidents but, hopefully, this can be excused on the grounds of youthful enthusiasm and a lack of knowledge at the time.

The Incidents

Learning about Runaway Exothermic Reactions (1970)

In 1970 I was involved in development work in the UK involving reacting hydrogen peroxide with olefins to make intermediates for new soap / detergent applications. Following bench scale work by chemist colleagues, I made experimental batches of the intermediates in a large (1-ton) batch reactor. The reactor was a glass lined vessel with an iron outer shell. Instrumentation was minimal – basic temperature indication. Cooling was provided by a water jacket. The reactor was situated in a blast proof building well away from other facilities. It was our approach to add all reactant in one step. An assistant and I were reacting a batch on one occasion when the temperature started to run away even with cooling on maximum. We had no idea what the outcome would be and fled the building. Luckily, there was no explosion, but the reactor contents were vented all over the countryside.

On investigation, we discovered a pinhole in the glass lining of the reactor and learnt what an excellent catalyst iron was for peroxide reactions.

Process safety at the time

No process safety existed at the time in the large UK chemical company. In development work the only safety requirement was PPE. The design of the buildings did demonstrate a basic understanding of the reactive nature of the materials. It is unknown whether the production side of the Company had better safety standards. There was no specific legislation at the time. ICI was starting to consider aspects of Process Safety like HAZOP etc.

If current PSM standards were applied

The following PSM elements would have applied:

- Asset integrity – equipment design / detection of leaks
- PSSR
- Exothermic reactions. Good practice in adding materials.
- Emergency Planning

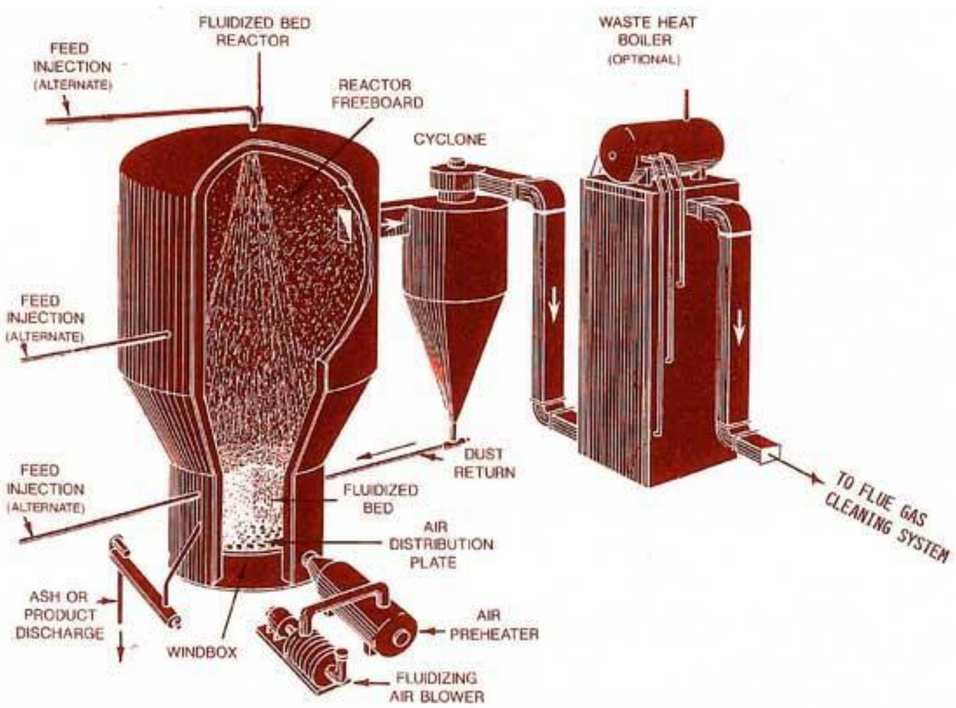
A Dangerous Start-up of a Standby Boiler Feed Pump for a Water Heat Boiler (1972)

In 1972 I was appointed as a plant manager and my first responsibility was the running of a new sulphuric plant. The process used iron pyrites from the mines. The process involved oxidising the iron pyrites in a fluidized bed roaster, recovering heat in the form of steam in a waste heat boiler, gas scrubbing, conversion of SO2 to SO3 in a catalytic converter and absorption of the gasses in weak sulphuric acid. The plant had numerous design problems and the plant availability was low. There was considerable pressure to maintain and improve production

I was in the control room when the main electric boiler feed pump failed. It could not be restarted. A standby diesel-powered pump was available. There was a rule that the cold water could only be put back into the boiler within 3 or 4 minutes of an interruption of water supply. There was concern over a possible steam explosion. Some time passed after the initial pump failure and after some 5-6 minutes the operators asked me whether they should start the pump. Without much analysis I instructed them to start the standby pump. They did so without a disaster happening. Failure to add water would have meant the certain destruction of the boiler tubes with the furnace heat being around 1100^{O}C and a 6-month repair period.

Figure 1 below illustrates the plant arrangement.

Figure 1. Position of the Waste Heat Boiler in the acid plant



Decision making and Process safety at the time

In this incident there was an understanding of the major hazard risks that were faced. Steam explosions were well known. There was clearly inadequate time to risk assess the decision to restart the pump. There was no requirement to do a risk assessment and there was no established technique for doing so. There is no doubt that the pressure to produce product was present and overrode the need to operate safely.

As the decision to start the pump was against the Operating Instruction, a safety violation took place (mea culpa). On the positive side, a rapid managerial decision was made.

Process Safety was still an unknown subject. There was no process safety legislation in South Africa (or the UK) at the time. There was no requirement to perform risk assessments or trained people to do same.

If current PSM Standards were applied

More serious attention would have been applied to the time limit after which the pump should not be started. It is likely that the standby pump would not have been started. This conservative approach would have resulted in certain tube meltdown and many months downtime.

There still would have been no time to do risk assessment on the pump. The consequence of a major boiler explosion would have been very severe with possible irreparable damage.

In today's process safety climate (and legal requirements) risks would have been identified by a suitable method like HAZOP. Pump failure would have been a standard cause for "No Flow". Should the adequacy of the safeguards been evaluated by LOPA, it is likely that the limited time to start up the standby pump would have been seen as inadequate and a standby pump would have been automatically started. Some type of trip system might have been suggested as well.

There would have been much more confidence in the ability to manage risks. At the time of the incidents risks were only perceived as a "gut feel".

Hazardous Entry into an Acid Mist Precipitator (EMP) to Remove a Shorted Starwire (1973)

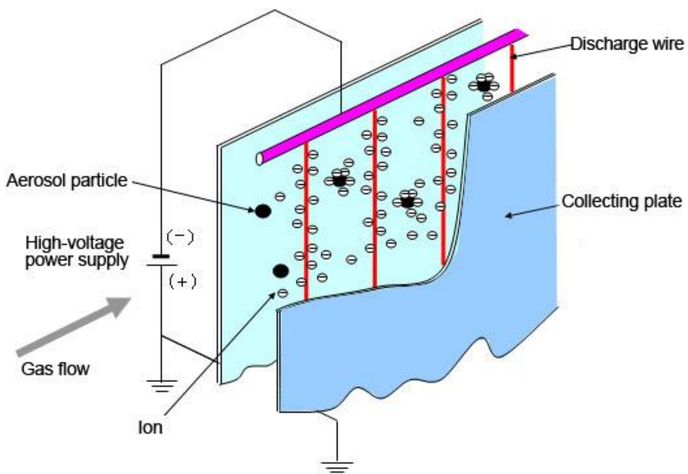
In the same sulphuric acid plant (see 2.2) I had a further learning experience. The off gas electrostatic precipitators which, when new, kept the stack plume invisible, deteriorated rapidly over weeks when the charged star wires were corroded by weak acid that was being precipitated. The wires and housing were made of mild steel. Some very poor design thinking! The precipitator was built in sections which could be electrically isolated when a wire was eaten through and shorted the compartment. A plume of off gas started to appear and became very heavy when most of the precipitator was isolated. On one occasion the Mayor of a town about 5km away arrived at the plant and requested me to shut it down. The plume was highly unpleasant to breathe, being a mix of SO^2 / SO^3 / sulphurous acid. There was great pressure to keep the plant on line somehow.

When a critical number of mist precipitator compartments were isolated, it was possible to run the isolated compartments if the offending shorted wire was removed. I decided, bravely or foolishly, to put on a full acid suit with an air supply and enter the precipitators and remove broken wires. We stopped the plant and I entered the vessel alone. There was no PTW or risk assessment done. A "buddy" guarded the entrance to the vessel. One entered the compartments through a hatch which had to be lifted up. I recall the acid level as being somewhere around my upper legs. There were many hazards in this task including the heavy hatch cutting off the air supply to my suit. I got the broken wires out and survived the task.

Later I realised that if anything had gone wrong, I probably would not have gotten out of the vessel alive.

Figure 2 shows the general arrangement within an electrostatic mist precipitator

Figure 2. Electrostatic mist precipitator internals



Decision making and Process safety at the time

There was no process safety legislation at the time. Occupational safety was well entrenched with good standards. A quasi-government body called NOSA set standards which were represented in a star grading system. Hazardous chemicals were recognised as an issue, but the only aspects of concern were the impacts on human tissues, incompatible materials, and toxic properties. MSDSs were only formally recognised in 1993 in South Africa. In the USA MSDSs were formalised in 1983.

The focus on Occupational Safety at the time is illustrated by a NOSA audit. At the foot of a 25000-ton anhydrous ammonia tank a NOSA auditor pointed out a guard problem on an ammonia pump. Probably to divert the inspector, I asked about the hazards posed by the ammonia tank. He stated clearly that he had no interest in the ammonia risk but that the guard was a problem!

My decision to enter the EMPs was clearly production taking priority over safety. There was time to assess the risk of entry, but this was not done because of lack of any methodology, trained people and a legal requirement to do so. Common sense should have suggested that there was a significant personal risk, but bravado / ignorance ruled the day. The PTW System was in place but was not seen to apply to Process tasks.

In spite of a few incidents my own perception of safety had not advanced much.

If current PSM Standards were applied

The task that was performed included the risks of:

- Entry into confined spaces
- Potential exposure to a dangerous substance (weak acid)
- Being trapped with no escape plan

A PTW would have applied to this situation although the need for a Permit is normally related to maintenance work. A Safe Working Practice could have applied here. The safest approach would have been to:

- Shut the plant down
- Isolate the EMP electrically and physically
- Drain the acid
- Open the EMP and ventilate
- Enter as per confined space rules

In the modern Process Safety era, common hazard identification methods like HAZOP or FMEA would have exposed the hazard and safeguards identified to deal with the operability issues. A different design should have been considered.

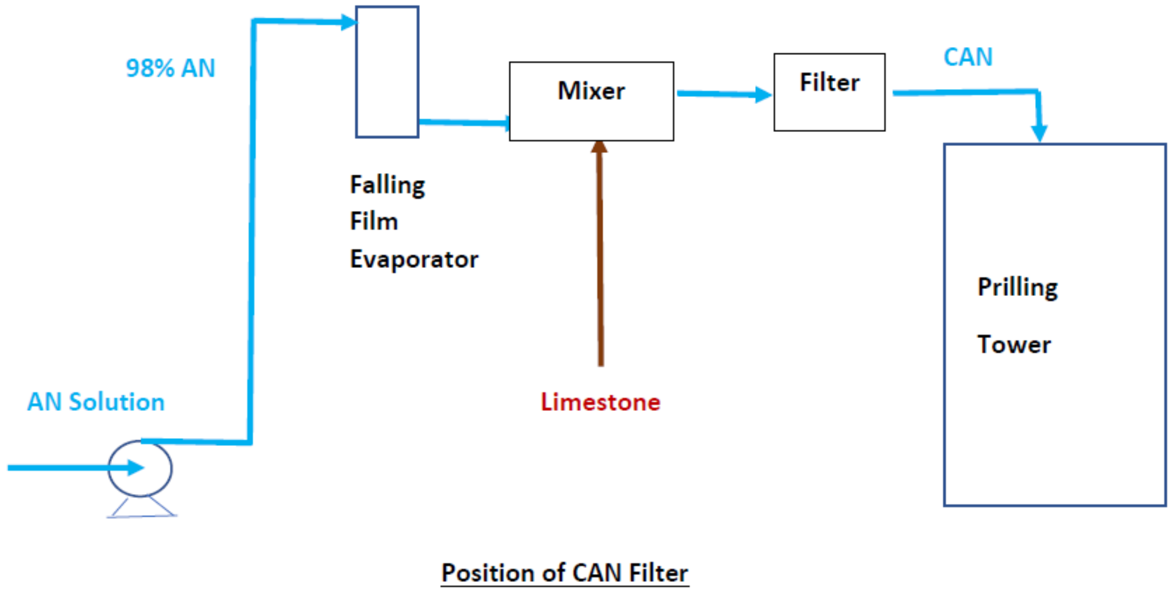
Installation of an Inline Filter on an Ammonium Nitrate Line – Unexpected Explosion (1980)

A new calcium ammonium nitrate plant had been built as part of a nitrogen complex but even 2 years after completion, gave serious operating problems. I was asked to see if I could improve the plant performance (I had developed a reputation for fixing ailing plants), so together with a technical team we made a number of significant changes and the plant started to run. Molten CAN solution was pumped to the headhouse of a tall prilling tower and prilled product recovered at the base. However, an ongoing problem remained in that the spray nozzles at the top of the tower clogged up regularly with oversize calcium carbonate particles and although all sorts of techniques such as knocking the sprays and vibrating them were tried, they failed. The thought dawned on me that we could filter out the large particles.

I designed an inline stainless- steel filter with a mesh size of probably around 1-3 mm. The filter was installed and looked like a fine piece of equipment. No MOC was done and no Risk assessments carried out. For about 3 weeks we had record production runs with no spray blockages. Then, on night shift, the filter exploded causing significant damage in the head house. No one was hurt.

On investigation we found that the filter had worked so well that it filtered out the oil in the molten stream and the oil had accumulated in the filter. The oil came from recycled material that had been coated with an anticaking agent. The arrangement is shown in the sketch below

Figure 3. Position of the filter in the CAN Plant



Decision making and Process safety at the time

There were no specific Process Safety Regulations in South Africa at the time (also UK and USA). There was a general awareness of the ammonium nitrate hazards because of the history of explosions over the years. There was a strong belief that ammonium nitrate containing 20% limestone was safe (Legislation in South Africa, Ireland and some Eastern European countries specified this level of diluent believing it was "safe")

Following Flixborough in 1974, the UK became aware of the hazards of modifications and, led by ICI, a de facto standard was adopted by most of the UK industries in 1975/1976. My company, through technical links to ICI, was probably aware of the approach to modifications but at the plant level we were unaware of the hazard and systems to control them.

At the time there was no requirement in SA for doing MOC, no legal requirement to do risk assessments for changes. Within the company there was no requirement to subject plant changes / modifications to review.

The decision to install a filter for molten CAN seemed a good one with no downside. Informal discussions did take place about the modification, but no issues were forthcoming.

If current PSM Standards were applied

Tests done by some fertiliser companies and the military showed that solid CAN can detonate under certain circumstances. Properties of the melt are uncertain but at the high temperatures reached before prilling, the melt is likely to be sensitive. The material would be considered more sensitive today.

A full MOC would be carried out on the installation of the filter. The HAZOP may have identified the issue with the oil accumulation but that is not certain. Modern practice is to avoid recycling product. Strict control over oil addition is exercised. The author is unaware of any specific reference to an explosion risk.

Modification of a Nitroglycerine Separator Leading to an Explosion with Eight Fatalities (1982)

The following incident was not under my direct control but as it developed, I became highly involved. My responsibility at that time was running a variety of chemical plants including one which dealt with the waste acid from the nitro-glycerine process. A colleague ran the explosives section and I ran the adjacent chemicals section. The whole company learnt some basic truths from the subsequent events.

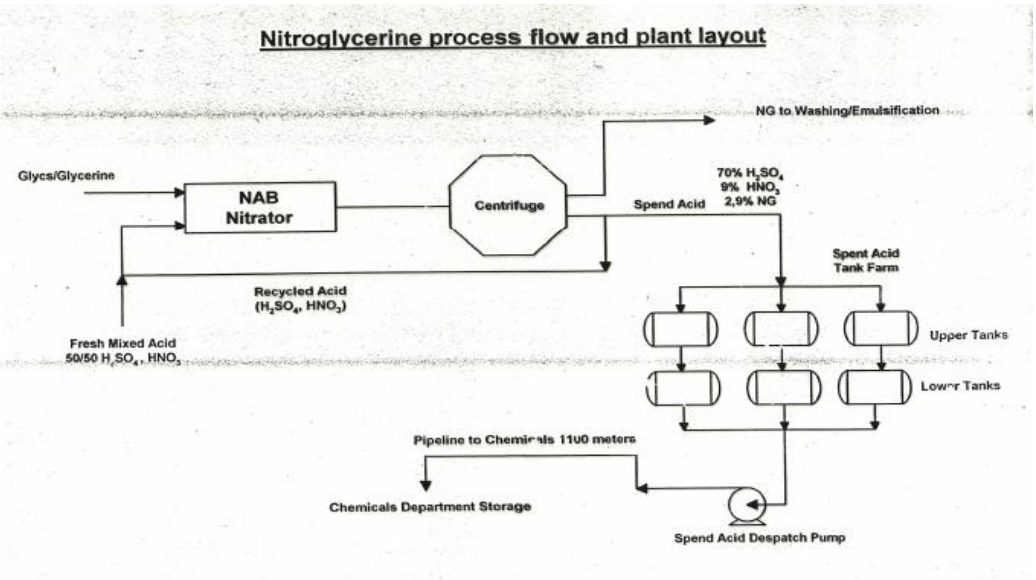
The old nitro-glycerine process involved reacting a mixed sulphuric / nitric acid stream with glycerine in a pipe reactor and then separating the heavy nitro-glycerine product from the lighter spent acid in a centrifugal separator. The two steams left separator at different points in the machine. The waste acid was run down to 6 x 80-ton tanks, from where it was pumped to my tanks about 1.5km away.

Late one afternoon, an explosives operator started up a centrifugal despatch pump near the weak acid storage tanks to send the acid to the Chemicals Department. There was an immediate explosion and the pump and much of the pipeline was destroyed. Sadly, the operator was killed in the blast. The situation was abandoned for the day / night. The next morning, about 10am, a team of technical staff and production people approached the weak acid tanks and in the course of their inspections, a much larger explosion took place killing all 8 people who were at the tanks. It is unknown whether an activity like sampling triggered this event.

On investigation it was found that the weak acid contained high levels of nitro-glycerine and was highly unstable. The reason for the nitro-glycerine being at such high levels was that the outlet pipe from the centrifuge had closed off and the NG exited with the weak acid. The offending piece of a pipeline was a short PVC section about 1 meter long and 1 cm in diameter. The type of PVC piping had been changed in the preceding months from a rigid PVC to a laminated form. The aggressive NG had delaminated the pipe and closed it off. There was no MOC done on this change.

Back in the Chemicals Department I found I had 320 tons of the same acid (that had detonated) right in the middle of a major chemicals complex. This was dealt with in a very innovative manner but that is a story for another day (or another paper). The flow layout is shown below.

Figure 4



<u>Decision making and Process safety at the time</u>

Two significant decisions were relevant to the incident. The first, a decision to replace the PVC type, was unknown to production and maintenance. There was no opportunity to review the merits of the change. Whilst MOC was in place in chemicals operations, it was not used in the explosives operations presumably because that application was seen as “different” where experience and worldwide explosives standards carried the most weight. There was no legal requirement to apply MOC in South Africa at the time.

The second decision was to allow a large number of people to be exposed to a potential major risk while starting the investigation. It is a fundamental principle in explosives that a minimum exposure is maintained at all times. Explosives Regulations embody the same approach. A significant judgement error was made. The gap of 18 hours since the first explosion may have led to a belief that no further explosions were likely. Nitro-glycerine is very unpredictable.

At the time Process Safety was not established as a discipline in South Africa.

<u>If current PSM Standards were applied</u>

It is understood today that Process Safety is applicable to all processes involving hazardous conditions and substances. The above example and the more recent Deepwater Horizon explosion (2010) show that there should be no exceptions. The Explosives Department rapidly adopted the elements of process safety (MOC) that were in use at the time. In particular, very small changes were recognised as being important. These included slight raw material alterations and materials of construction. There is still concern today in companies that change can be initiated from areas unfamiliar with the MOC system like Purchasing and suppliers.

A risk assessment would be applied to this situation.

In modern process safety thinking, the need for “chronic unease” by management should prevail and extreme caution applied to approaching mass storage of material that had exploded earlier. This heightened sense of danger was evident when the 320 tons of the same sensitive material was dealt with in the Chemicals factory.

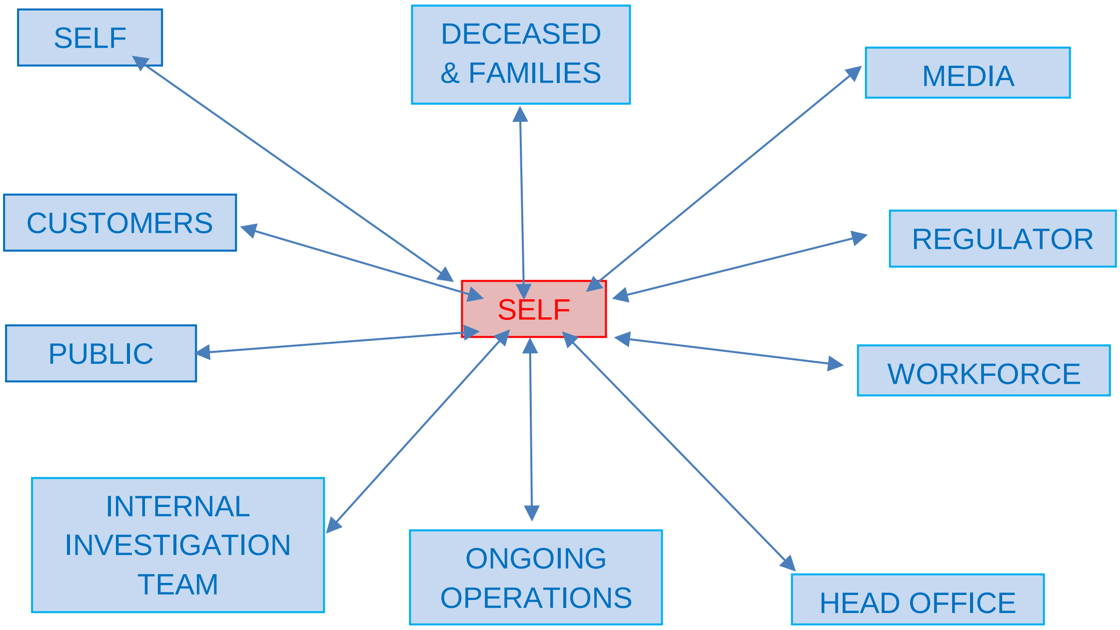
Dealing with the Aftermath of a Major Nitroglycerine Explosion with Seven Fatalities (1994)

Later in my career, I was appointed as Production Director of the Explosives (commercial) operations. These plants easily created the sense of “chronic unease” which is a popular concept today. At that time, the full range of explosives products were made including the popular Dynamite and Dynagels as well as more modern products based on ammonium nitrate.

Near midday on a particular day, I was in my office when a massive detonation occurred, and I felt the ground shockwave and heard a blast. When I saw the cloud rising above the explosives works, I knew a major incident had happened and I was in charge. Very sobering.

I drove the scene and observed fires burning in the nitro-glycerine production houses. We did not approach too closely in case there were secondary explosions. Later in the day when we met with the emergency services and medical personnel, we established that 7 workers had died in the incident. We had communicated with the Regulator, local police, local Head Office and local CARE Committee that we had an incident with fatalities. It was made clear that dealing with the aftermath was going to be my responsibility. Whilst we had carried out Emergency Planning including simulations it soon became clear that the complexity and extent of the responses of external and internal bodies was way beyond any of our plans and imagination. The diagram below shows the sectors that had to be dealt with:

Figure 5. Sectors that needed attention following the explosion



Deceased and families

Families were brought to the Site from rural areas. They were accommodated and cared for. This was largely dealt with by the HR Manager / staff who also provided counselling services and advice on benefits available. My role was to show sympathy from the senior management level and check that any issues were dealt with. There was some experience of this within the company, so it was well handled.

A memorial service was held soon after the event. Speakers at this emotional event, Trade Union officials, ministers, politicians and myself representing company. Without being directly threatened, it was an uncomfortable experience. There is no training for this task.

Media

The event was headline news on TV, radio and newspapers. It became clear very soon that journalists did not want to speak to our PR staff. All sorts of tricks were employed to get me or another senior manager to appear in front of the cameras and microphones. We had TV training. Helicopters appeared over the explosion site. This was illegal. The secretaries had their work cut out to keep unwanted journalists out.

When the enquiry was underway, the reporting was sensational in the extreme. Objectivity was minimal. Headlines like "Killer Blast" and "Untrained workers" (untrue) were seen. It was very easy to get angry with the reporting. Whilst this was not totally unexpected, it was more extreme than expected. Emergency planning did not prepare one for this.

Public

Many phone calls were received from the public including from people who lived nearby. Specific phones were designated for these calls and they were well answered by a prepared senior manager. Liaison with the communities surrounding the site had been well established over many years. The CARE Committee which represented the local people, was kept well informed. These arrangements worked well.

Customers

A few days after the incident, a major customer informed us that he was giving our main competition half of the business as we were "unreliable". A Marketing delegation paid them a quick visit and convinced them that we had sound alternatives to supply them. This reaction was unexpected and not planned for. It was helpful to have developed excellent customer relationships in the earlier years.

Workforce

Immediately after the incident the 3500 strong work force went on strike demanding danger pay. There was a militant element which did some damage to infrastructure. This situation created a tense atmosphere affecting all post incident activities. I appointed a senior manager, who reported to me, to lead a management team to negotiate with the Union / workforce. This work continued in parallel to other activities. There was never any intention of granting any employee danger pay as this would set a dangerous precedent. We had a cushion of several weeks stock to back up our negotiating stance.

I was asked to address a mass meeting of the strikers who put a variety of questions to me. This was a tense experience as there was a threat of violence.

The calm approach of the negotiating team won the day and the workers came back to work after 3 weeks.

The strike and aftermath were not anticipated in Emergency Planning.

Ongoing Operations

The incident created a lot of uncertainty and concern through the rest of the site. Whilst only skeleton staff was still available to operate plant, regular communications took place on developments following the incident. Managers, many of whom were doing operating work, spent extra time with the remaining employees who were working.

Regulator and public enquiry

We had a sound relationship with the Regulator (Chief Inspector of Explosives). His Department collected much written evidence and had reviewed all the physical evidence. Interviews were carried out with many managers and workers. A list of people to be interviewed in Enquiry was submitted to us.

The Enquiry was held in a Magistrates Court and was chaired by a Magistrate who had some experience of industrial disasters. The public could attend the hearings and the media were well represented.

The company was represented by an external legal firm with extensive experience in industrial disasters. We were well briefed particularly on what not to say.

The prosecution was led by the Regulator. Other lawyers represented Unions and workers. Proceedings were slow but systematic. Two days were spent proving all the deceased were trained. There was a difficulty because some paperwork had disappeared.

The Enquiry lasted a week. There was no finding regarding the cause of the incident and a minor paper work fault drew a small fine for one of my managers.

The Enquiry was unpleasant with lawyers not really understanding technical matters.

As a manager, I had never received training in this aspect of the job.

Internal Investigation

As the Regulator had the objective of establishing whether any laws (Regulations) were broken with regard to the incident, the Enquiry was inadequate in establishing the root causes of the incident and therefore eliminating a reoccurrence.

The company had a policy of full investigation of all incidents with the objective of preventing repeats. A parallel investigation was set up under the leadership of one of my managers. The Regulator had all the information requested by him but nothing extra was volunteered on advice by our lawyers. The internal investigation had access to all information which included extra information.

A very uneasy situation prevailed for a few weeks as the two investigations continued in parallel. There was a concern that the "official Enquiry" could demand all the internal investigation material.

The internal investigation failed to reveal any root causes of the incident

Head Office

The local Head Office was very supportive supplying resources and moral support.

The overseas Head Office was different. It only requested to be "kept informed". No support was provided, and it was learnt later that firing of myself or my superior, the MD, was considered.

An overseas technical team was sent out later. Some slippage of our safety standards was detected.

The overseas involvement was seen as very political.

Self

Being in charge of all activities resulting directly from the explosion, I had to ensure that we managed on a number of fronts. Luckily, I had several able managers to whom I could delegate discrete parcels of work. For some weeks we met daily to review progress and develop new plans. The MD was kept informed of progress and problems.

The management of the aftermath of the explosion was my most serious management challenge in some 30 years in the chemical industry. Because of threats, real or perceived, I had 24 hr body guards. Stress levels were very high. Sleep was difficult for weeks. At that time trauma counselling was not well known and I resisted taking medication.

The incident produced many challengers which are not normally planned for in Emergency Planning whist the personal requirements to deal with a major event are not covered at all. Perhaps, through a case study approach, people could be better prepared for a worst-case scenario.

Process Safety considerations

Many of the elements of Process Safety were in place at the time but they were not integrated in a PSM System. Emergency Planning and Response had been a key managerial concern for many years, and this did not change because of Process Safety developments.

With hindsight, better planning would not have made much difference, but the experience of the incident and its aftermath gave all insight into new aspects that needed attention.

Conclusions

It is clear that having a production career in hazardous industries over a long time exposed one to dangerous and testing incidents particularly in the pre "formal Process Safety Management" era.

My experience covered a variety of processes and substances. I would confess to being production (output) focused in my youth and was prepared to take risks to keep plants going. Safety, as we knew it, took a back seat. Companies and individuals today (including myself) have a very different view of priorities. It has taken many accidents and changes in legislation around the world to achieve this.

The case studies illustrated in this paper show how differently situations would be handled today. There are many more tools available for us to determine risks and ensure sufficient controls are put in place. We should not have to wait for another accident to get all of us to move to best practice.

My own learning covered both technical issues (properties of ammonium nitrate), and organisational / people aspects. Some of these lessons were not apparent at the time.

Hopefully, the case studies will also have exposed some learning points for those who may not be familiar with the described situations or substances. It should also be clear that we do not always have full knowledge of hazards and there can be still be surprises. Of course, people at the workplace and those affected by incidents are always capable of surprising the most experienced and professional manager.

Acknowledgement

The assistance of T. Frederick, an ex-colleague is recognised. His memory and records of some of these incidents was often superior to mine.