Accidents and their Role in Aiding the Management of Health and Safety in Pyrotechnics Manufacture

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The opinions expressed in this article are those of the author and do not necessarily reflect the position or policies of the Health and Safety Executive. Information about accidents in this article without specific references is based on the author's personal knowledge or information contained in the Explosives Accident Database Advisory Service (EIDAS).

ABSTRACT

The investigation and analysis of the causes and circumstances of accidents can be an invaluable tool in assessing the effectiveness of systems for the management of health and safety. This article considers and draws on the lessons learned from a number of accidents to suggest a general framework to aid the development of management systems for the manufacture of explosives. While the emphasis is on firework and pyrotechnic manufacture, the issues have wider application.

Keywords: safety management, pyrotechnics, health and safety, manufacture

Introduction

The dangers associated with the manufacture of explosives have long been well recognised as has the need to control the consequences arising from accidents. Historically the intuitive response has been to minimise the risk of communication of any explosion between process and storage buildings and to ensure that the public is not put at risk. The question of the safety of employees did not feature strongly in the minds of early regulators.

In the UK, the first attempt to provide control of explosives manufacture came with the gunpowder Act of 1772. This Act set out limitations to the amounts of explosive that may be involved in any manufacturing process and set out minimum distances between process buildings and places outside the factory. This concept was extended in the Gunpowder Act of 1860, which implemented more detailed provisions and introduced a requirement for a licence to manufacture gunpowder, mercury fulminate, percussion caps, fireworks and other preparations or compositions of an explosive nature. The Explosives Act, 1875 (EA 1875)[1] developed the licensing requirements further and ensured that its provisions covered all explosives. This most recent act also made a real effort to provide some reduction of risk to employees through general and special rules.

In spite of the efforts of EA 1875, there was still a tacit acceptance that those working in a factory would, from time to time, be involved in an explosion. When such an accident occurred, the response was “well they knew the risks”. This “laissez faire” attitude was exemplified by an article in the Strand Magazine in 1895 describing a visit to the government gunpowder factory at Waltham Abbey.[2] The article commented on the thoughtful provision by the factory operator of a water filled pond outside a process building to enable any worker involved in a fire or explosion to jump in and extinguish their burning clothes. The fact that workers were likely to be involved in an explosion didn’t warrant comment.

This system of control is simply not acceptable by modern standards. It is no longer reasonable that workers in explosives factories, just because they are prepared to work with explosives, should accept lesser standards of protection than workers in other industries. Of course there will be risks but it is incumbent on the operators of any factory to ensure that the safety of their employees is adequately managed through the reduction of risks to an acceptable level and the provision of adequate protection from the effects of any accident that might nevertheless occur.

The current approach in the UK to controlling the dangers arising from explosives manufacture and storage therefore relies on a two-layered approach:

1) The licensing of explosives factories and magazines, limiting the processes that may take place in any building, setting amounts and types of explosive in each building, and defining the separation distances between buildings and from places outside the site. This follows the concepts described above and has its origins in EA 1875. Provisions in EA 1875 also require the occupier of a licensed factory or magazine to draw up and implement general and special rules. These set out restrictions on how activities may be carried out thus seeking to limit the risks of an ignition. The rules are required to be endorsed by an explosives inspector, a process that limits the ability to modify or adapt the rules on a day to day basis to address new safety issues that might arise.

2) The assessment and management of risks and hazards by the operators of the site to minimise the danger to those working in the factory or magazine. This draws on wide duties placed on employers and employees stemming from the Health and Safety at Work Act, 1974 and the Management of Health and Safety Regulations, 1999. These controls require employers to operate safe systems of work and to conduct and implement risk assessments aimed at reducing risks to health and safety to "As Low as Reasonably Practicable" (ALARP). Factories and magazines handling large quantities of explosives are additionally subject to the Control of Major Accident Hazards Regulations, 1999 (COMAH). Top tier sites under these regulations are required to prepare a major accident prevention policy, a safety report and an on-site emergency plan.

The inspection of explosives factories and magazines by the Health and Safety Executive routinely examines levels of compliance with both of these areas.

Management of Health and Safety

Much has been done to set out an environment in which factory operators can develop and implement systems for the management of health and safety. A significant amount of work has taken place in the UK over the last 20 years producing guidance on the general aspects of safety management, risk assessment and human factors.[3–5] Additionally, specific guidance on the safe management on specific high risk operations has been produced.[6] Tools and guidance have been developed to enable manufacturers of explosives to estimate the potential effects of their activities and to provide suitable protection.[7,8] Where poor safety performance has been identified, auditing techniques have been applied at senior company levels with good effect identifying failings in management.

Under the broad title of "Loss Prevention", the analysis of accidents and the lessons they offer to the development and refining of safety management has become a common tool. Accidents are, in effect, a demonstration of the ineffectiveness of management and control systems. Accidents and their root causes can shed a great deal of light onto the failures of safety management systems and teach lessons on how these may be improved. Trevor Kletz has shown this in his work relating to safety in the general chemical industry, and I have found his books to be a valuable source of common sense advice on plant design and operation. The application of root cause analysis techniques to the investigation of accidents can pay dividends in the development of safety management and control systems.

In this article I want to examine a number of accidents that have occurred in the pyrotechnics industry in the UK and draw out the lessons learned and what they tell us about key issues in the effective management of safety.

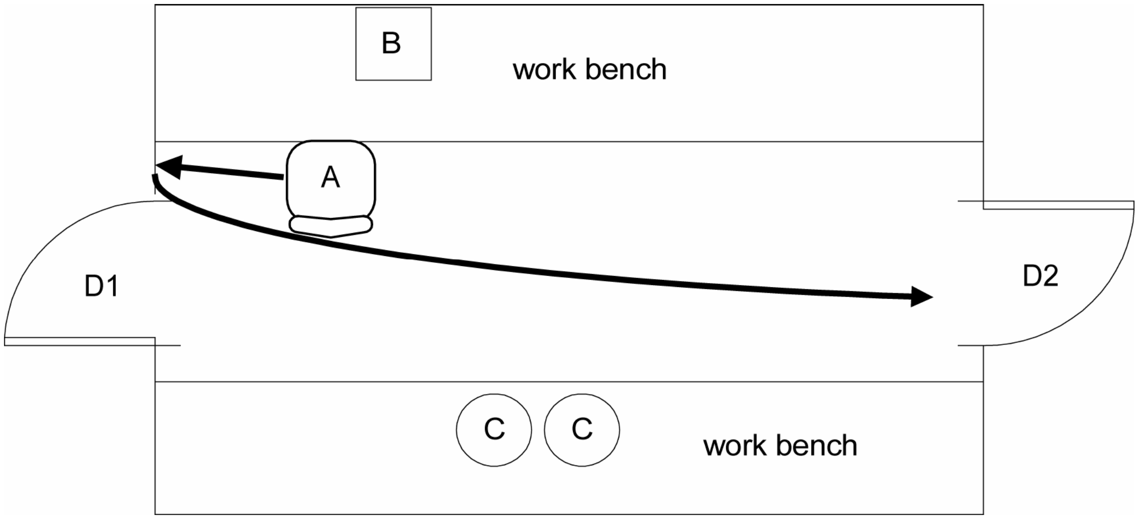

Figure 1. Process building floor plan.

Accident 1

A company was involved in filling gerbs with a blackpowder/titanium mixture. The process involved incremental filling using a drift and mallet. The building involved was of normal construction with a door at each end and was licensed for 50 lb (23 kg) of composition. The general building layout is shown in Figure 1. The workman sat at point A, next to one exit door and had a stock of composition in a work box on the bench at location (B). Two stock containers, C, were located on the bench behind the workman. An ignition occurred during the filling of a gerb, and the fire spread rapidly to the composition in the workbox and in turn ignited one of the stock containers of composition.

The workman turned to his left and moved to leave through the door D1 but in the confusion and smoke he ran into the wall instead of the door. He assumed that he had turned the wrong way. He therefore turned back into the building and crawled on his hands and knees past the burning stock container. He escaped through door D2 but was severely burned on his back. The bold arrows show his overall route.

The building contained 50 lb (23 kg) of stock composition but did not exceed the licensed building limit at the time of the accident. Although 50 lb (23 kg) of composition was not required in the building, the runner who delivered fresh composition during the day had delivered a double amount to save a journey.

The issues arising from the accident are simple:

1) Although they did not exceed the licensed limit for the building, the company had not kept the amount of composition to a level consistent with safe operation. A safe system of work would require only the amount of composition necessary for the work in hand to be present at any time.
2) The work boxes used in the building were not self closing, meaning that the initial ignition spread rapidly. Had the boxes been well sealed and self closing, the initial ignition might not have escalated. It is interesting that one of the two plastic stock containers did not ignite proving the benefit of well fitting lids.
3) The company did not have an assessment of the sensitivity of the composition to impact or friction and was not able to demonstrate that the method of filling was appropriate.
4) The accident demonstrated how easy it is to get confused in a fire and how careful design of building layout might help assist escape.

Accident 2

Joseph Green, a safe maker, ran a "small firework factory" in his spare time. The concept of the "small firework factory" is peculiar to the EA 1875 and perhaps requires some explanation. Provision was made under the Explosives Act for local authorities to licence "small firework factories". The law prescribed in some detail what was permissible in terms of buildings, safety distances, allowable activities and quantities of explosives.

The factory in this case was comprised of two process sheds and a magazine. Mr. Green was involved in making "Five Pointed Stars". The report quoted from a pyrotechnist's textbook that was current at the time:

Five Pointed Stars: These are cases about 2 1/2 inches long and 1 inch diameter. Make a bottom to the case with 1/4 inch thickness of plaster of Paris, so that it looks like a large pill-box. Charge it solid and at 3/8 inch from the extremity, that is, 1/8 inch beyond the plaster bottom; round the circumference make five holes as for Saxons; run a bit of match round connecting the holes. These, when fired, stand out at right angles, the plaster towards the spectator, so that the fire resembles a gas fire, with five points.

The cases described were normally made from paper.

The composition usually was comprised of meal powder, sulfur, potassium nitrate and antimony sulphide and when filled in the method described was generally considered by the firework industry to produce a relatively mild firework.

Mr. Green had decided to "improve" on the design by using a tube made from brazed iron or steel sheet. He also decided to fill them with red and green fire composition. Subsequent analysis of the residues suggested that the composition used probably contained barium nitrate, potassium chlorate, sulfur and possibly some carbon.

A five pointed star exploded as Mr. Green was filling it, killing him. His injuries were clearly a result of blast and shrapnel, his hand being amputated and his femoral artery cut.

The lessons are fairly clear:

1) Any attempt to change a design must be analysed carefully and any resulting change in risk or hazard assessed. In this case, the use of a steel or iron container introduced a frictional hazard that Mr. Green did not appreciate. This hazard was increased by the use of a much more sensitive composition.
2) Mr. Green had been holding the firework as he was filling it. He had no protection at all from the effects of the explosion.
3) Mr. Green was no more than a hobbyist with little understanding of the science of pyrotechnics. He simply wasn't competent to judge the suitability of his actions.

Accident 3[9]

Work commenced at 8 am one morning on the filling of 4-1/2 inch (115 mm) rockets in building B6. This was a new product, a trial filling having been carried out the day before. Three women were carrying out this work. The process involved filling tubes with a rocket composition (70% potassium nitrate, 20% charcoal and 10% sulfur). Once filled, the choked ends of the tubes were drilled using a hand drill fitted with a steel drill bit. Drilling was usually done once all filling was complete and then only by one person in the building.

Because the women had little experience in rocket production, they asked the foreman to carry out performance tests on the rockets. The test proved unsuccessful and a further quantity were bored and tested. These tests were successful. It was decided that some further tests would be performed on rockets filled in B6 that day. The layout of the building at the time of the accident is shown in Figure 2.

Filling continued in building B6 during the morning. At approximately 12:30 pm Mr. L., the person tasked with carrying out the further tests, went into the building. He took a tray of filled rockets and placed them on the left of table B. He was located at point 3. At that time there were 5 lb (2.3 kg) of FFF grade gunpowder in a box on table A; on table C there was a partly completed rack of rockets and 1 lb (0.5 kg) of composition; on table B, there were two filled frames and 5 lb of composition; and there was one filled frame of motors and 5 lb of composi-

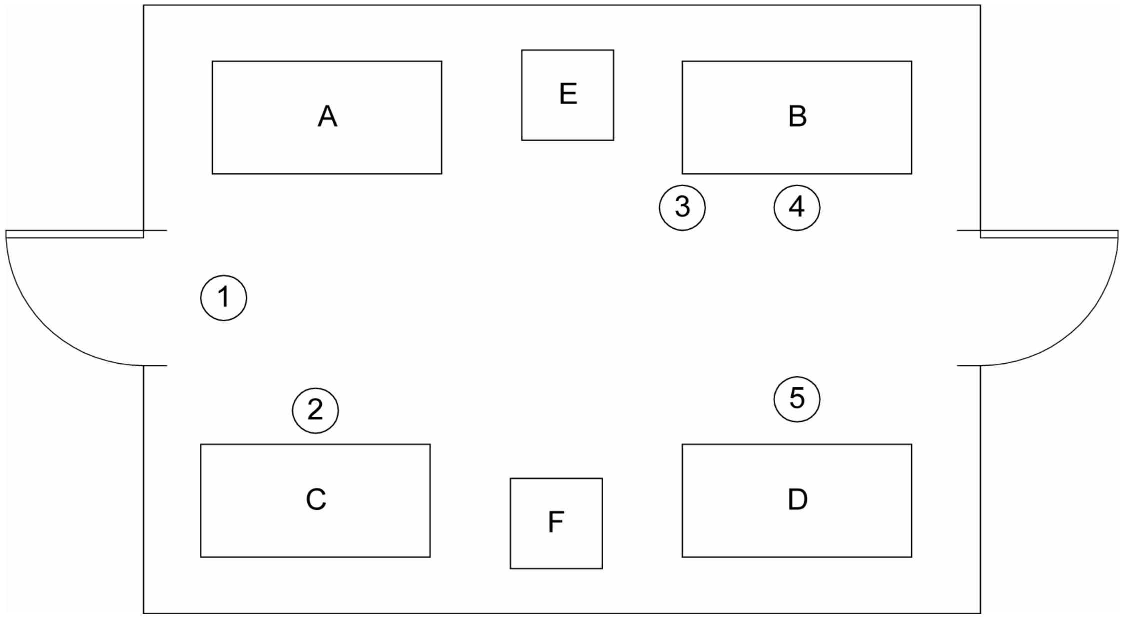

Figure 2. Process building floor plan

tion and on table D. Overall it was estimated that there were 76 lb (35 kg) of composition in the building, well in excess of the 50 lb (23 kg) licensed limit.

Mr. L. had bored two motors and was in the process of boring a third when it ignited. The ignition communicated almost immediately to the gunpowder on table A. The accident resulted in the death of Mr. L. and the women at work positions 2 and 5 with injuries to two other people. The foreman, who was present just inside the building when the ignition occurred, made no comment on Mr. L.'s activity in the building.

The causes and contributory factors are easy to see:

1) The building was overstocked and held explosives not required for the job in hand. The gunpowder on table A was for banger production. This material significantly increased the severity of the accident.
2) The use of a hand drill was not a suitable method of boring rockets. The usual method was to use a cone-shaped bronze needle operated by a lever or a foot treadle. The composition was found to be sensitive to steel on steel, and the suspected cause of the accident was ignition by the drill breaking.
3) The boring should have taken place in a separate building where filling was not being done.
4) The technical knowledge of the supervisory staff was found to be inadequate. The foreman had a total of 12 weeks experience in fireworks manufacture. There were significant failures in supervision.

Accident 4[10]

The building involved in this accident comprised of a series of 4 compartments in a row (A to D). The licence for the building was slightly unusual in that it allowed the use of both chlorate and perchlorate based compositions and compositions not containing these substances, provided that only one type was in use in all the compartments at any time.

At the time of the accident, compartment A was not occupied but contained 25 to 30 lb (11 to 14 kg) of explosive. Compartment B was not in use for manufacture but was being used to help with the transfer of fireworks. It contained between 236 and 300 lb (107–136 kg) of fireworks. Compartments C and D were being used for the filling of bangers. Compartment C was occupied by one woman and held between 100 and 115 lb (45–52 kg) of fireworks. Compartment D was occupied by two women and held between 135 and 160 lb (61–73 kg) of fireworks.

A supervisor of the building was working in another building but walked over to the building concerned to ask the time. He went into compartment B to check whether more tea chests were needed. As he entered the compartment, he saw a flash under a bench behind the steam pipe. He fled the building seeking help. There were two explosions destroying the building and spreading fire to other buildings. All three women were killed. The official investigation and report concluded that the most likely cause of the ignition was grit on the shoes of the supervisor. The key issues were damning:

1) The building was hugely overstocked. The official report estimated that the total inventory of explosives in the building was between 430 and 650 lb (195–295 kg) whereas the licensed limit was 145 lb (66 kg). The report also concluded that the three women would have had a better chance of escape if the inventory had been within the licensed limits. The amount of explosive was such that communication between the compartments was rapid.

2) Many of the operatives did not use protective overshoes. The supervisor who probably caused the ignition admitted that he never wore overshoes. It was suggested that workers were only required to wear overshoes when the government inspector visited. Management claimed that they found it difficult to make workers wear overshoes.

3) There was no effective system to prevent prohibited items such smoking materials from being brought into the factory.

4) Workers were allowed to wear their own clothes, which were often made from man-made fibres and had pockets.

5) A lack of effective control was observed with a tendency by management to disclaim personal responsibility for compliance with the licence and other legal duties. The investigating inspector was satisfied that the conditions applying on the day of the accident were typical for the factory. The accident was inevitable.

Accident 5

A fire occurred in the early hours of the morning burning out a compartment in a process building. The building was unoccupied and no one was hurt. The cause of the fire was a smoke formulation that had spontaneously ignited. The composition contained potassium chlorate, ammonium chloride, kaolin and a resin. Previously the mixture had been wetted with an alcohol and had not presented any problems. The company had changed the process electing to use a solution of gum in water.

The likely cause of the ignition was a chemical reaction between the potassium chlorate and ammonium chloride producing unstable ammonium chlorate—a reaction that required an aqueous environment in order to take place.

This accident demonstrates that it is crucial to understand the chemistry of your compositions. The arbitrary switch from an alcoholic to an aqueous wetting agent had led to a dangerous chemical reaction, which caused the fire. The control and recording of change is particularly important in areas such as research and development and plant design, typical issues being effects of new sources of ingredients, change in processing sequence or conditions and the effects on change in plant behaviour.

Accident 6

A factory had been temporarily closed and was being completely cleared of explosives. A worker had been assigned the task of collecting materials, tools and equipment and moving them off site. The worker was asked to help move rubbish to the burning ground. Paper and other non-explosive waste were being burnt on a bonfire. Nearby was a stack of match frames that were contaminated with blackpowder residues. The worker decided, on his own initiative, to burn these frames off by placing two at a time on the edge of the bonfire and then retrieving them once they had burnt off. He dealt with six frames this way and was carrying another two frames towards the bonfire when they ignited. The ignition spread to the stack of frames (60 frames in all). The worker received burns to his hands, face, neck and midriff (where his jumper and jeans did not meet).

It is not difficult to envisage that the ignition was almost inevitable. The sad fact is that the worker had received no instructions on how to dispose of the frames and, indeed, no instructions to dispose of them.

Accident 7

A fireworks company was asked by another company to dispose of some waste pyrotechnic articles. A test burn showed that the articles burned slowly and agreement was given to burn the main consignment. This work proceeded all day without incident. A second consignment arrived by lorry the following month and its contents were unloaded into a building. This time there seemed to be a mixture of the pyrotechnic articles with containers of composition. Half the load was burned without incident.

Some months later the weather was considered suitable to deal with the remaining half of the second load. The material was laid out and the company director attempted to light the fire with a hand flare. This failed and he took three port fires, lit them and threw them onto the waste. As he turned away the waste ignited with a large fireball, which set his clothes on fire and burned his legs, arms, shoulders and face.

Although a test firing of the original load had been carried out, the company didn't carry out a similar check on the second load, even though it contained composition in addition to the waste articles. The director clearly underestimated the hazard from the second load and stood too close to the waste when he ignited it.

The Lessons from these Accidents

It doesn't take profound analysis to identify the key issues arising from these accidents and their importance to adequate control and management of the manufacture of pyrotechnics—the messages are there for all to see. The question is how do they fit into a wider management structure? It is useful to gather the issues from these accidents into a structured form. These can be listed under a number of key themes, which can be used as a framework for the development of a suitable safety management regime. These themes are listed below.

To those readers whose job includes the management of workers and their safety, "Do you recognise these issues? Do your procedures encompass them? How well does your company address them?"

Competence

- Are workers trained? Not only in terms of the nuts and bolts of the process but also the basic safety issues relating to handling and manipulating explosives and energetic materials in general?
  - Do they understand basic safety procedures?
  - Do they know how to use personal protective equipment correctly?
  - Do they understand the limitations imposed on any given process building?
  - Do they understand why things are done the way they are?
- Are supervisors competent? Not only the issues outlined in the previous paragraph but are they experienced? Have they done the work prior to being promoted?
- Do senior managers have technical competence? Do they understand the basis and rationale behind the safety systems in use? Do they recognise and respect the role of the lower managers or is there a tendency to interfere or over-rule when the occasion or company demands suit them?
- Does your company have a framework of competences identified for each post with a training regime to ensure that employees gain the necessary skills and knowledge? Do you use succession planning to ensure that, when employees leave, trained staff is available to fill the posts if they are vacated?
- How do senior managers ensure that they keep abreast of technical developments, new standards, legislative requirements and industry good practice? Is this information cascaded effectively to staff?

Technical Understanding

- Is the chemistry of the formulations and processes well understood?
- Have the hazards of materials been assessed [e.g., explosive properties, flammability, toxicity, sensitization (e.g., dermatitis, asthma)]?
- Have the properties of the materials (such as sensitiveness, stability, flash points, and other key properties) been assessed?
- Are there procedures in place for monitoring and controlling change in process or materials? How are changes to processes, materials or plant assessed prior to implementation? Is there a system of control and peer review to prevent unauthorised change? Are changes recorded along with the reasons for the change?

Management of the Processing Environment

- Based on the known hazards of the materials are the processing conditions appropriate (e.g., clean areas, overshoes, electrostatic protection, specially made tools)?
- Are hazards controlled to minimise danger to operators? The usual hierarchy of controls in order of priority are:
  - Prevent exposure—options include enclosing the hazardous material, using a less hazardous alternative, remote operation, etc.
  - Use adequate control—minimise the amount of material in process, use Local Exhaust Ventilation (LEV), self closing work boxes, etc.
  - If adequate control cannot be achieved, use Personal Protective Equipment (PPE)—including screens, fire proof clothing, masks, gloves, leather wrist protectors, respirators, machinery guarding, etc.
- Have noise level surveys been carried out (e.g., at proving and test areas)?
- Have all hazardous substances been assessed and control measures identified?
- Are the systems of protection and control based on risk assessments?
- What systems of supervision and control are in place to ensure that the needs of the processing environment are met? For example, appropriate issued clothing and footwear are worn, contraband is excluded, and operating rules and controls are met.
- How are controls implemented? Constant presence of supervisor or spot checks. What inspection regime is in place? Posting of manufacturing and operating instructions. Training of operators. Tool box talks. Is the reporting of "near misses" encouraged (or even mandatory)?
- Manual handling training.
- Routine health monitoring (e.g., blood lead monitoring).
- Maintenance. Provision of suitable tools and equipment. Use lists. Permit to work systems.
- Cleaning. Decontamination. Procedures when changing formulations. Exclusion of incompatible systems (e.g., chlorate with sulphur).

Risk Assessments

- Have risk assessments been prepared for each of the processes taking place?
- Do the assessments include the following elements:
  - Identification of hazards. Are recognised hazard identification tools such as Hazard and Operability (HAZOP) and Hazard Analysis (HAZAN) used?
  - Some method of scoring and ranking hazards.
  - The identification of controlling or mitigating actions.
  - The assessment of the residual risks once controls are applied and comparison to established standards for tolerable risks (in the UK the concept of ALARP is used to assess the acceptability of risks).

- The application of additional controls until the residual risks are acceptable.

- Is there a robust system for reviewing risk assessments to accommodate change such as in process or formulation?

Burning Grounds

Burning ground activity can be a particular problem area and statistics show that accidents due to lack of control are a major issue. Disposal and burning are frequently seen as being activities not requiring the same level of control and rigor as manufacture. It is somehow perceived as being less hazardous. The reality is that disposal presents a range of issues that are unique and potentially very severe. Frequently the explosives will be in a form not usually encountered in processing. They may be in bulk, under confinement or mixed with other explosives, which can cause a synergistic enhancement of hazards. Assessment of hazards and effective systems of work are crucial.

The disposal of explosives and waste ingredients will inevitably require consideration with regard to long term effects. For example, an accident occurred in the UK where waste ingredients from a firework factory had been buried and the site capped with concrete. After a lengthy period of time there was an explosion. Water seeping through the soil had reacted with metal powders in the waste leading to the evolution of heat and hydrogen.

Finally

A number of incidents are given below with a little detail; I leave the reader to ponder this question:

If you were the manager of a factory and you had had any of these accidents, what actions would you take to prevent them in the future?

- Two lb (0.9 kg) of an experimental mix for stars was sent for destruction. The trial ground staff added a further 4 lb (1.8 kg) and attempted to destroy the lot. On ignition, a detonation occurred. There was no injury to plant or personnel other than 16 factory windows being broken.
- An attempt to extinguish a magnesium fire with a water extinguisher resulted in an explosion that removed the roof of the laboratory and an adjacent wall.
- Pressed stars of a composition including barium nitrate, potassium perchlorate and aluminium ignited spontaneously in an expense magazine during warm weather. A strong smell of ammonia had been noticed in the magazine some minutes previously.
- A tray of 96 formed stars was set to dry with one end resting on the heating system. A spontaneous ignition subsequently occurred—fortunately nobody was injured.
- An ignition occurred as a process worker was using a brass scraper to remove a deposit of blackpowder and nitrocellulose that had built up on the floor of a building used for drying igniter cord. The ignition spread to the contents of the drying compartment.
- A quantity of match composition, which had been mixed by hand, ignited as it was passed through a sieve. The fire spread to other explosives in the compartment and thence to an adjacent compartment. One man died from burns.

Conclusions

Usually the reaction when reading accident reports is “How could they let that happen?” or “It’s obvious you don’t do that.” The simple fact is that accidents do happen whether through carelessness, poor management, slack controls or simply inexplicable behaviour. It’s easy to spot the issues when reading reports on accidents that have happened. It’s not always so simple to spot them before the accident occurs.

Hopefully the lessons from these incidents will strike a chord and, whether you are a manager or actually involved in manufacture, they will raise questions in your minds and prompt you to challenge and possibly change how you do things.

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Other Useful Publications

The following publications provide useful information on managing safety and the provision of protection.

Fire Protective Clothing—A Guide to those Who Manufacture or Store Pyrotechnics or Propellants, Confederation of British Industry [ISBN 0-85201-513-5] 1995.

Hearing Protection—A Guide to those Who Manufacture, Test or Use Explosives, Confederation of British Industry [ISBN 0-85201-548-8] 1997.

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