USE OF DATABASES: ANALYSIS OF INCIDENT TRENDS AND INCIDENT CAUSATION

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ACCIDENT TRENDS IN EXPLOSIVES MANUFACTURE

If history shows that hazardous activities rarely run accident free it also shows that these activities can be made safer over time. An example of this phenomenon, which I'm sure will be of direct interest to most people here today, is air travel!

The graph below shows the general fall, worldwide, in the fatal accident rate for airline operations in the period 1985 to 2005 [1].

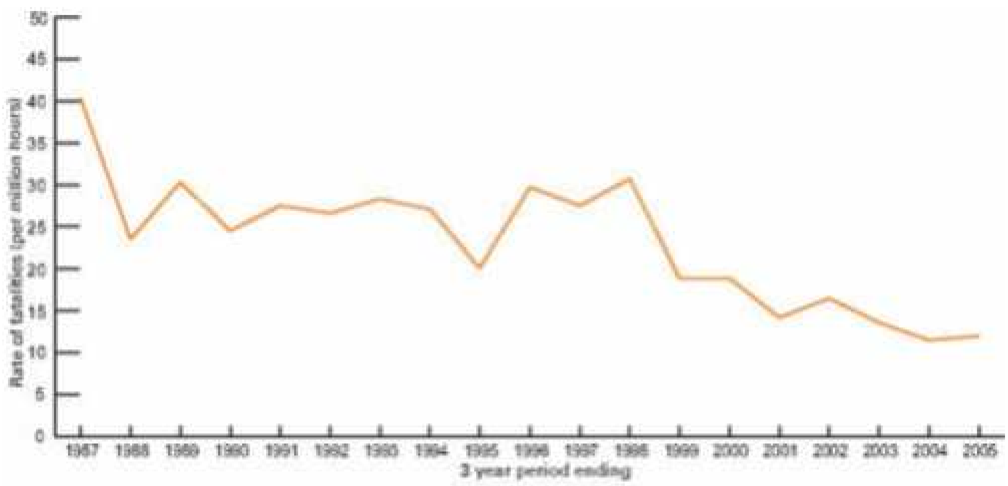

Figure 1: Rate of Fatalities Worldwide – Large Western-built Jets (3 year moving average) (Civil Aviation Authority, 2010).

An overall downward trend in the fatality rate in the 20-year period is clearly discernable. The downward trend is not smooth – there are a few blips here and there – but an overall improvement in safety performance is seen over the measured period.

The question arises: can we detect a similar pattern in our own industry? At this point a problem is immediately encountered. Although data for fatal incidents are available, the difficulty is that we do not have the corresponding worldwide employment data to allow calculation of accident rates of the type shown in Figure 1 – i.e. numbers of fatalities per million working hours.

In view of this difficulty, it is necessary to fall back on analyzing raw accident statistics. Nonetheless, a trend may emerge from a comparison of the number of fatal accidents and the total number of fatalities reported in explosives manufacture in different time periods, though the significance of any such trend may be open to debate.

For the purpose of this paper, fatal accident statistics have been compiled from the EIDAS Database (Moreton et al. 1996), of which SAFEX is a major contributor. The data set

[1] For Western Built Jets with a maximum take-off weight greater than 5,700kg (excludes business jets). Third party fatalities, such as fatalities on the ground are also not included.

includes accidents in the manufacture of military and industrial explosives, military and industrial pyrotechnics, propellants and ammunition, but excludes accidents in the manufacture of fireworks.

The data are presented graphically in Figure 2, which shows the number of fatal accidents and fatalities reported in each decade in the period 1950 to 2009.

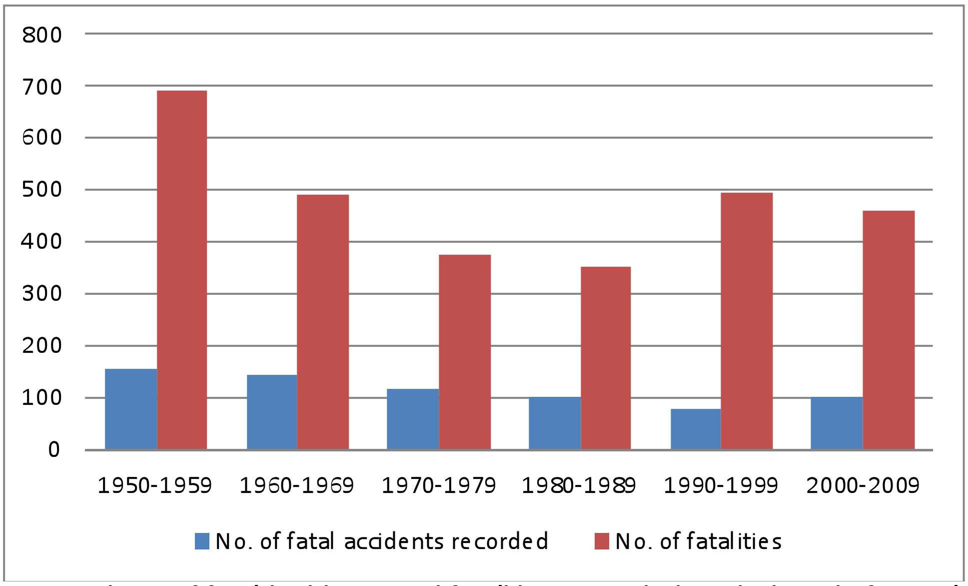

Figure 2: Numbers of fatal incidents and fatalities recorded each decade for explosives manufacture worldwide – 1950-2009

At first glance this chart looks quite promising, but three points should be borne in mind before it is considered in more detail.

Firstly, the point is made again that in order to make a proper evaluation of safety performance the raw accident statistics should be converted into fatal accident rates, otherwise any trend shown by the statistics may reflect changes in levels of production over the period rather than any improvement or deterioration in safety performance.

Secondly, there is no claim that the data set is comprehensive. The EIDAS Database has been compiled from many different sources of information, including official government records, industry records, text books, learned journals and news reports; but there is no guarantee that it contains a record for each fatal accident that has occurred in the period to which Figure 2 refers. I do believe, however, that the EIDAS Database is the most complete source of information on explosives incidents currently available, and that most major accidents that have occurred in the last 60 years will have been identified in the extensive searches that have been undertaken in compiling the database.

Thirdly, a number of records have been encoded from news reports, and the casualty figures recorded in some of these cases may only be approximate.

The above caveats notwithstanding, the chart does show a gradual decline in the number of fatal accidents recorded in each decade (blue shaded area) of the last half of the 20th Century. A similar pattern is observed in respect of the total number of fatalities reported (brown shaded area) but there is a blip for the 1990s. This blip is largely due to an exceptional accident that occurred on the 30th November 1991 in North Korea, in which 200 people were reported killed in a massive explosion at a missile plant. If this incident is removed from the statistics, then the total number of deaths recorded for that decade reduces to fewer than 300 and it will be seen that the downward trend is then back on track.

The first decade of the 21st Century appears to buck the trend, however. Thus in 2000-2009, just over 100 fatal accidents were recorded, which represents an approximate 25% increase on the previous decade. But can this be taken as evidence of a deteriorating safety performance? At this point it is as well to sound a few notes of caution.

Firstly, the apparent increase in accidents in the last decade may be explained, at least in part, by a better capture of information than was obtained in previous decades. Certainly, the Internet has provided access to many news sources, particularly those in the developing world, that were not readily accessible in the previous century.

Secondly, the decline in accidents over the period 1950-1999 may reflect a contraction in the explosives industry, particularly in the developed world, and may not be entirely due to increased safety performance.

To probe these issues further, it is instructive to examine the fatal accident record for explosives manufacture in two developed countries along with that for two countries in the developing world. The countries in the developed world are the UK and USA, for which I believe we have very good incident data; while the countries in the developing world are China and India.

The data for the UK and USA are shown in Figures 3 and 4 respectively.

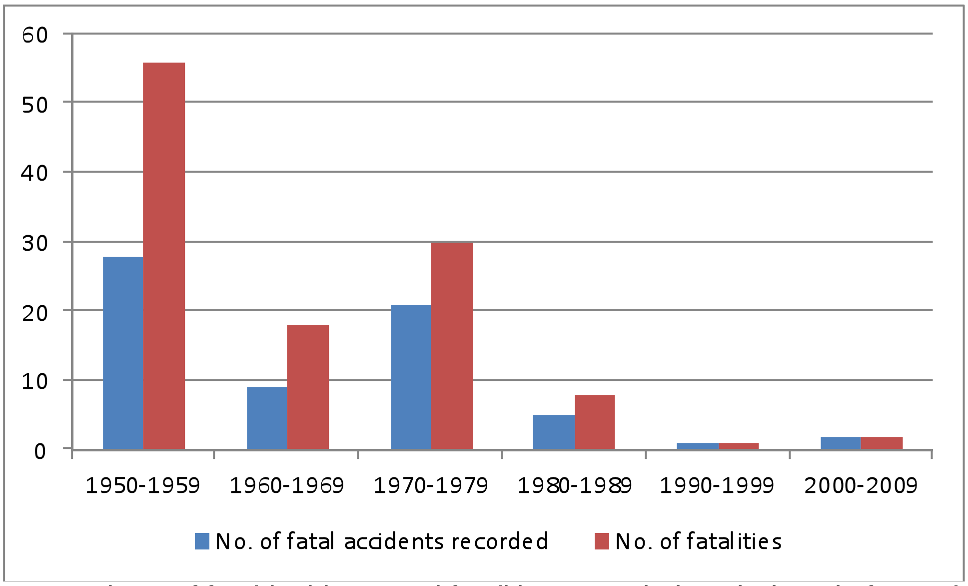

Figure 3: Numbers of fatal incidents and fatalities recorded each decade for explosives manufacture UK – 1950-2009

In the case of the UK there has been a marked decline in both the number of fatal incidents reported and the number of fatalities recorded in each decade over the last 60 years (though there was a blip in the 1970s for reasons that are not immediately apparent). In the 1950s, just under 30 fatal accidents were reported, compared with only one such accident in the 1990s and two in the last decade. It has to be said that this decline has coincided with a massive contraction in the UK explosives industry. As evidence of this it may be noted that in 1950 there were 87 factories licensed to make civil explosives, but by 2009 the corresponding number had dropped to 16 [2]. Furthermore, many of the factories that have survived operate at much lower levels of production than in former days.

The figures for the USA show a similar pattern.

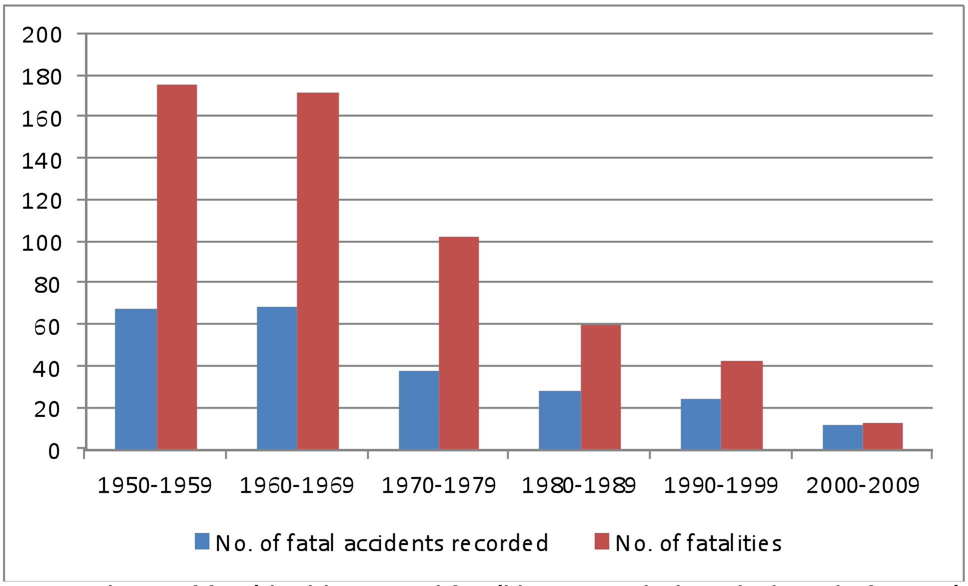

Figure 4: Numbers of fatal incidents and fatalities recorded each decade for explosives manufacture USA – 1950-2009

The statistics for the 50s and 60s are similar, but in every decade since there has been a decrease in both the number of fatal accidents and the overall number of deaths resulting from those accidents.

Again the question arises: to what extent is the downward trend shown in Figure 4 due to declining production? This is an area that requires further research and is beyond the scope of the present paper. It is suggested that individual members may wish to determine fatal accident rates for their own operations over the decades to see if any trend emerges.

There is no doubt that if we were to extend the period of study back to the beginning of the last century, then a gradual improvement in safety standards and performance will be evident. There is much anecdotal evidence for this. For example, in 1905 an explosion in a dynamite plant in Pequea, Pennsylvania, in which 11 people were killed, was reported to have been caused by a cigar. Incredibly, one report of the incident (G S Biasutti, History of Accidents in the Explosives Industry) noted that "smoking was not forbidden in the factory and even the nitrator operator used to lay his lit cigar on the edge of the apparatus". Surely it is inconceivable that such an event would happen today.

[2] This figure excludes ordnance factories, small fireworks factories, toy fireworks factories, magazines, stores and registered premises, but includes large fireworks factories where compositions are mixed, pressed, filled, etc. The figure for 2009 does not represent the total number of factories currently licensed by HSE; rather it is a comparative figure derived by judgment, as licensing arrangements in the UK have changed significantly over the period.

In fact, an examination of Figures 3 and 4 reveals that the number of people killed per fatal incident has reduced sharply over the decades. In the 1950s, fatal incidents in explosives manufacture in the UK and USA resulted in between two and three fatalities on average; whereas fatal incidents in the last decade rarely resulted in more than one fatality. This is largely explained by automation of processes and development of new, safer types of explosives. In this regard very real improvements in safety have been made.

These measures are important as it would appear that it is difficult to eliminate completely the potential for certain types of fault to occur in manufacture. The presence of foreign objects in process equipment is an example. This type of fault has been the cause of scores of ignitions in explosives factories over the years, particularly in the manufacture of gunpowder and pyrotechnics. Indeed, the last such incident was reported as recently as 2009 (see SAFEX Incident Alert IN32-09). In such cases there is a need to ensure that personnel would be fully protected in the event of an ignition – by remote operation, for example.

The pattern for the developing world is the exact opposite of that for the UK and USA. The data for China and India are shown in Figures 6 and 7 respectively.

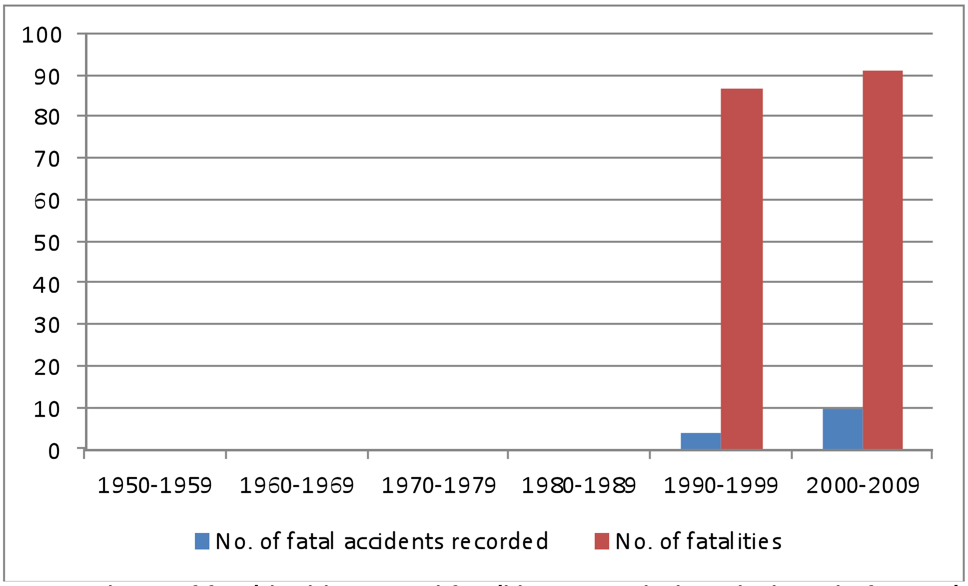

Figure 6: Numbers of fatal incidents and fatalities recorded each decade for explosives manufacture China – 1950-2009

The first thing that will be noticed from Figure 6 is the absence of any records of fatal accidents in the period 1950-1989. That is not to say there were no such accidents, but rather that we have no records of any such accidents. In the 1990s information began to emerge about a handful of major incidents, some of which resulted in very large numbers of fatalities. For instance, on the 9th Feb 1991, there was a report of a massive explosion in a TNT plant that claimed the lives of 17 workers (Zhang 1993). There was a report of an even worse incident two years later, when 61 people were killed in an explosion at a factory making emulsion explosives.

A similar pattern is noted for India.

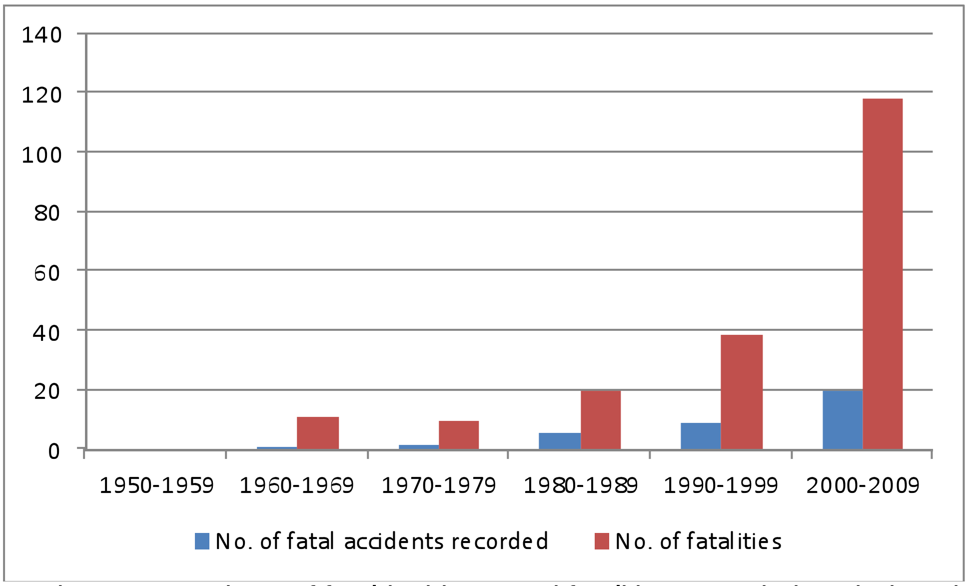

Figure 7: Numbers of fatal incidents and fatalities recorded each decade for explosives manufacture India – 1950-2009

There are no reports of any fatal accidents occurring in the 1950s; but then from the 1960s onwards there is a decade-on-decade rise in both the number of fatal accidents reported and the numbers of fatalities arising from those accidents. Some accidents have been truly catastrophic. For instance, on the 5th of May 2007, an explosion in a factory making small diameter cap-sensitive emulsion resulted in 21 fatalities – a presentation on this incident was given by one of our members at the Madrid Congress (Gupta 2008).

It is interesting to compare the data shown in Figure 7 with corresponding data for usage of explosives in India. The following graph shows the extent to which consumption of explosives in India has increased over the last 80 years.

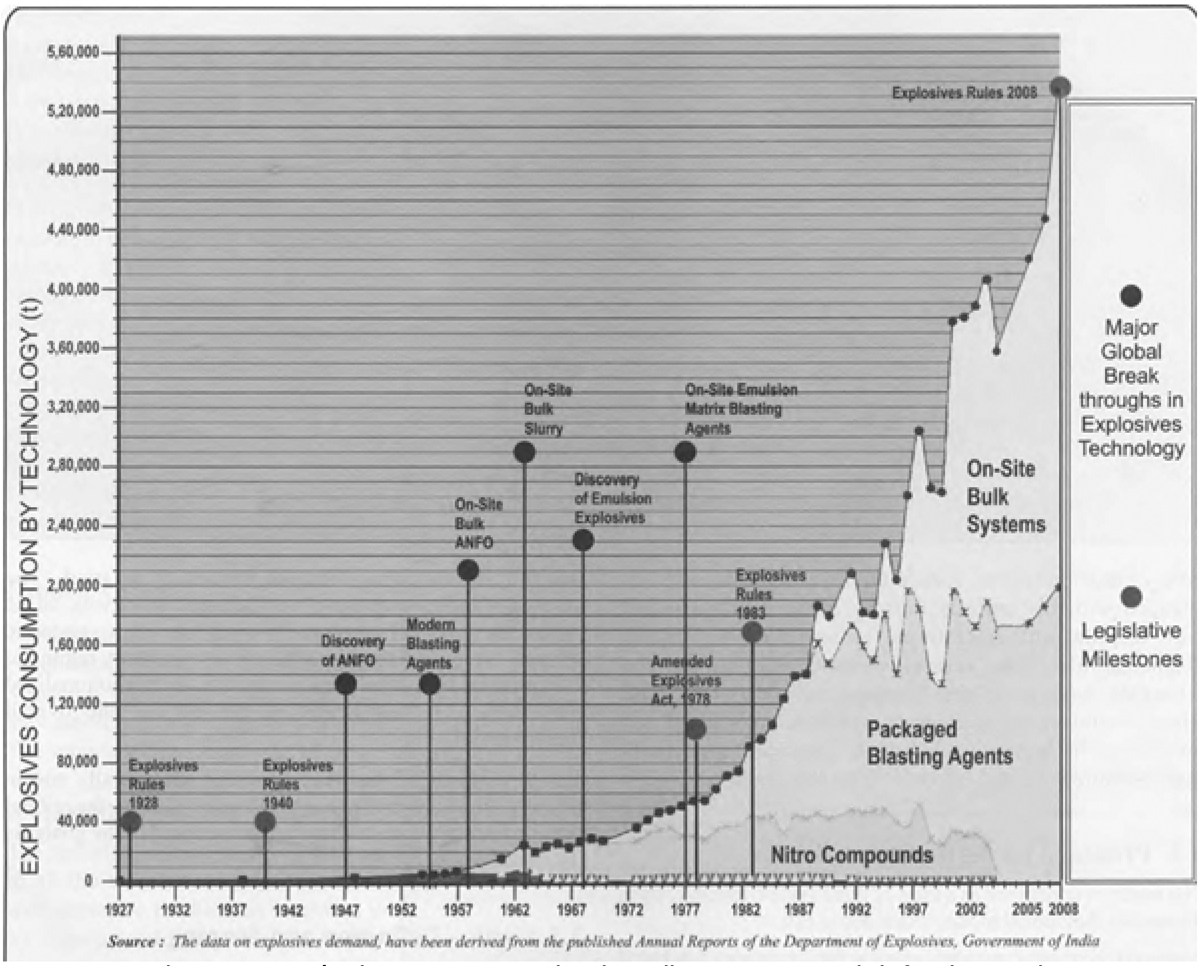

Figure 8: Explosives Consumption in India 1927-2008 (Visfotak 2009)

By comparing the data shown in Figures 7 and 8 it will be seen that there is a very good correlation between the quantity of explosives consumed and the number of fatal accidents reported in their manufacture. Thus between 1975 and 2005 there was approximately a ten-fold increase in the quantity of explosives consumed, and this is matched by a ten-fold increase in the number of fatal accidents occurring in manufacture. It is likely that the data for China also primarily reflect increased economic activity in recent decades rather than any change in overall safety performance.

The other striking feature about Figures 7 and 8 is that the average number of people killed per explosives incident is high. No doubt a number of factors contribute to this pattern, including relatively large numbers of workers involved in process steps, e.g. raw material handling and packaging, and the carrying out of many operations in one or close buildings, i.e. without unitization of risk or adequate quantity-distance protection.

The data presented so far paint an ambiguous picture in regard to changes in the safety performance of the explosives industry worldwide in the post-war period. There is some evidence to suggest an improvement in certain sectors, but more research is required to determine the extent of any improvement.

Of course, the rate of occurrence of fatal accidents and the overall numbers of fatalities resulting from these accidents are not the only measures of safety performance. We could also look at a number of "safety performance indicators", such as the number of unintended ignitions during manufacture and number of "near-miss" incidents. The problem here is that reliable data for these incidents are more difficult to come by; certainly there appears to be a "reporting gap" as mentioned in the quarterly SAFEX Newsletters.

One thing is clear, though, and that is if the safety performance of the industry is to improve with time, then it is vital that the lessons learnt from past accidents are acted upon and are not forgotten.

ANALYSIS OF INCIDENT CAUSATION

Today, electronic databases play a very important role in preserving information on past accidents and the lessons learnt from them. In the UK, the need for an explosives-incidents database was recognized in the 1980s, following studies by both the UK Health and Safety Executive (HSE) and the Explosives Storage and Transport Committee of the UK Ministry of Defence (ESTC) into the risks of transporting and storing ammunition and explosives. The reconstruction of historical accident records formed an important component of these studies and in both cases the task was made difficult and time-consuming by of the lack at that time of a single, comprehensive source of accident data.

The HSE subsequently commissioned the EIDAS system in the late 1980s (The ESTC became joint sponsors shortly afterwards). EIDAS provides a service that collects information on incidents, analyzes that information and stores it in a readily accessible and retrievable way. The system has now been running for over 20 years and during that time a considerable effort has been expended in encoding details of past and on-going incidents, both in the UK and worldwide. The database currently holds details of almost 20,000 incidents going all the way back to the first recorded gunpowder mill accidents in the 17th century.

To date, EIDAS has been used for a number of purposes, including:

- Providing input for the HAZID component of risk assessment studies, i.e. as a means of identifying the immediate and root causes of potential incidents

- Monitoring the safety of activities involving explosives and hence identifying areas that require special attention,

- Assisting incident investigations

- Providing data to validate explosion effects models

- Providing a service to officials seeking information about specific incidents

- Aiding the preparation and evaluation of Safety Reports required under the Seveso II Directive.

It is the first of the above aims that I wish to explore today.

A risk assessment of an explosives manufacturing process normally begins with an attempt to identify the potential faults that could arise with the process. A number of techniques may be used for this purpose, including HAZOP and FMEA. However, always a good point to start is by looking at what has gone wrong with the process in the past. In fact, in my experience a Past Accident Review will often identify potential faults that HAZOP and other HAZID techniques miss.

The Past Accident Review process crucially depends on the existence of high-quality databases that encode all pertinent details of accidents. In other words, the quality of incident reporting is key to the success of the process.

One of the sessions later this morning will look at examples of good and bad reporting. In the opinion of the author, the current SAFEX incident reporting template provides an excellent format for recording all pertinent details of incidents. Very briefly, this template requires:

- Specification of the date and location of the incident: this information is necessary not only to allow future auditing of the record, but also to allow the database to be searched by date and location for the purpose of compiling statistics.

- Process outline: two of the search fields on the database cover type of process, i.e. blending, nitrating, pressing, etc. and type of explosives. Clearly, the process needs to be described in sufficient detail for these fields to be filled accurately.

- Description of the incident: the circumstances of the incident need to be described in sufficient detail to allow logical inferences to be made about the immediate and root causes of the incident, though it is appreciated that exact causes cannot always be determined. Information on the timeline of the incident and the quantities of material involved can help in the understanding of the sequence of events leading to ignition and the effects of the ignition.

- Impact of the incident: firstly, numbers of fatalities and injuries need to be specified. Information on the nature of injuries sustained by persons at various distances from the ignition will help in our understanding of explosion effects. The protective effects of PPE are certainly worth recording. Where applicable, information on crater dimensions, blast damage to property at various distances from the explosion and debris throw can help improve explosion effects models. Photographs of damage are always useful.

- Likely cause of the incident: the conclusions of the incident investigation should be stated. If the exact cause of an incident cannot be determined, it is helpful if the various possibilities are reviewed and likelihoods assigned to the various possibilities (with explanations).

- Actions to prevent recurrences and learning points: this section is obviously of key importance. One of the major objectives in carrying out a Past Accident Review is to obtain an assurance that that the lessons learnt from past accidents have been properly assimilated into both the design of equipment and procedures employed in the process under review.

The Past Accident Review process requires that a series of questions be asked in respect of each incident report examined.

Firstly, could the faults described in the report be repeated with the process under review?

Secondly, if so, what controls are in place to try to prevent the identified faults from arising or to ameliorate the consequences of those faults?

Identification of controls in turn requires critical analysis to be applied to each identified accident scenario (for example, broken blade in an incorporator). The relevant questions are:

1. What controls are in place to prevent the identified fault from arising?

These controls may include both engineered measures and procedural measures. For example, the engineered measures against broken mixer blades might include: (a) the blade is not fabricated from welds so as to minimize the possibility of inherent weaknesses; (b) the blade is of very high tensile strength – made from stainless steel of a specified standard and roughness, (c) the blade unit is welded to the kneading shaft. While procedural measures might include: (a) the blade is x-rayed for defects before despatch to the site and then again after arrival on the site; (b) the blade is x-rayed during service every time the seals are changed – for example, every 10,000 hours of operation (equivalent to 5 years' normal running) or following the manufacturer's recommendations (c) blade clearance checks are carried out prior to the start of operations.

2. What controls are in place to prevent ignition in the event that the identified fault does occur?

Again these controls may include both engineered and procedural measures. For example, in the case of a foreign object getting into the mixer, a number of engineered measures may prevent ignition. For instance, a torque limiter would stop the process should an object lodge between the blade and the wall of the mixer. Procedural measures may include training of operatives to respond correctly to alarms sounding or flashing in the control room (i.e. training to a recognized level of competence). The explosives formulation itself may be an important factor in ensuring safety: high explosives generally are designed to withstand considerable insults without igniting, but in such cases reference should always be made to relevant trials or laboratory data to show that an identified fault (e.g. nipping of explosives between the rim and lid of the mixer) would not cause an ignition.

3. What controls are in place to limit the effects of an ignition?

Again these controls may include both engineered and procedural measures. Engineered measures may include installation of drenchers (to ensure that an ignition would be extinguished quickly); pressure-relief systems (to prevent an ignition going high-order, i.e. to prevent deflagration to detonation transitions); detonation traps (to prevent an ignition propagating down a production line), passive water protection (to act as a blast suppressant); or the building may be designed to TM5-1300 standards to unitize the risk.

4. What controls are in place to protect personnel in the event of an ignition?

Engineered measures would include remote operation from control rooms that are designed to offer occupants a high degree of immunity against the effects of an ignition. The guarantee of remote control may in turn depend on captive key systems, micro-switches and time locks – again critical analysis is required of the reliability of these measures. Procedural measures may include use of PPE and evacuation procedures.

The Past Accident Review process can be aided by checklists of a type shown in the table below. Such checklists are in turn compiled from analyses of incident reports.

Energetic stimulus	Generic fault condition	Specific fault condition	Root cause
Impact or friction	Foreign object	Foreign object in raw ingredients	Failure of QA process
Impact or friction	Foreign object	Foreign object introduced by operative	Process Instructions ignored
Impact or friction	Foreign object	Foreign object introduced by operative	Sabotage
Impact or friction	Foreign object	Foreign object from equipment	Poor design/maintenance of equipment
Impact or friction	Foreign object	Fall of fixture/fitting	Poor design/maintenance of process building
Impact or friction	Blade/paddle hits wall of mixer	Equipment incorrectly set up	Inadequate training; Process Instructions ignored
Impact or friction	Blade/paddle hits wall of mixer	Faulty equipment	Poor design/maintenance
Impact or friction	Blade/paddle hits wall of mixer	Lightning causes programmable controller malfunction	Inadequate lightning protection (LPS or surge arrestors) Poor design of software modules in PLC
Impact or friction	Blade/paddle hits wall of mixer	Material hardens in mixer paddle	Process Instructions ignored Poor design/maintenance
Impact or friction	Blade detaches from mixer	Faulty equipment	Poor design/maintenance
Impact or friction	Abnormally sensitive mix	Ingredients added in incorrect order	Process Instructions ignored
Impact or friction	Abnormally sensitive mix	Ingredients added in incorrect order	Failure of automated systems
Impact or friction	Abnormally sensitive mix	Incorrect amounts of ingredients added	Process Instructions ignored
Impact or friction	Abnormally sensitive mix	Failure to add specific ingredient	Process Instructions ignored
Impact or friction	Abnormally sensitive mix	Ingredients excessively lumpy	Failure of QA process
Impact or friction	Abnormally sensitive mix	Incorrect amounts of ingredients added	Failure of automated systems
Impact or friction	Abnormally sensitive mix	Incorrect particle size of ingredients	Failure of QA process
Impact or friction	Abnormally sensitive mix	Process operated outside of design parameters	Process Instructions ignored

Table 1: Part of an accident checklist for blending/mixing operations

CONCLUSION

This paper has looked – very briefly – at the use of electronic databases for analyzing trends in safety performance and for performing HAZID via Past Accident Review. Access to high quality data is of paramount importance in both cases, and this in turn depends on good practices in accident reporting. This theme will be explored further in the next presentation.

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