

ACCIDENT INVESTIGATION – MISSED OPPORTUNITIES

Trevor Kletz
Department of Chemical Engineering, Loughborough University LE11 3TU, UK

After paying the high price of an accident, we often miss opportunities to learn from it:

- We find only a single cause, often the final triggering event.
- We find only immediate causes and do not look for ways of avoiding the hazards or for weaknesses in the management system.
- We list human error as a cause without saying what sort of error though different actions are needed to prevent those due to ignorance, those due to slips or lapses of attention and those due to non-compliance.
- We list causes we can do little about.
- We change procedures rather than designs.
- We do not help others to learn as much as they could from our experiences.
- We forget the lessons learned and the accident happens again. We need better training, by describing accidents first rather than principles, as accidents grab our attention; we need discussion rather that lecturing, so that more is remembered; we need databases that can present relevant information without the user having to ask for it.

Finally, we ask if legislation can produce improvements.

Keywords: Accident investigation, discussions, training, human error, databases, memory.

…the ICI knowledge was no more prodigious than elsewhere, just that the company was prepared to be more open about it. – Jim McQuaid[1]

INTRODUCTION

The chemical industry is a much safer place to work than many industries with fewer inherent hazards[2]. Nevertheless, almost all the accidents that have occurred need not have occurred. Most of them have happened before and have been described in published reports. Someone knew how to prevent them even if the people on the job at the time did not. There is something seriously wrong with our safety training and the availability of information if preventable accidents keep on happening.

Having paid the price of an accident, minor or serious (or narrowly missed), we often neglect the opportunity to learn from it. Failures should be seen as educational experiences for both the individual and the organisation. Seven major opportunities, summarised above, are frequently missed, the first five during the preparation of the report and the other two afterwards. Having paid the "tuition fee", we should learn the lessons.

ACCIDENT REPORTS ARE OFTEN ONE-DIMENSIONAL

Often, accident reports identify only a single cause, though many people, from the chemist who chose the process, through the designers, down to the last link in the chain, the operator, had an opportunity to prevent the accident. The single cause identified is usually this last link in the chain of events that led to the accident, such as an operator closing the wrong valve or a mechanic breaking the wrong joint.

Just as we are blind to all but one of the octaves in the electromagnetic spectrum so we are blind to many of the opportunities for preventing an accident. We find one cause and say, "Job done".

ACCIDENT REPORTS ARE OFTEN SUPERFICIAL

Even when we find more than one cause**,** we often find only immediate causes. We should look beyond them for ways of avoiding the hazards, such as inherently safer design, and for weaknesses in the management system. For example, could less hazardous raw materials have been used? Could more safety features have been included in the design? Were the operators adequately trained and instructed? If a mechanic opened up the wrong piece of equipment, why wasn't there a better system for identifying it? Saying, "The pump you repaired last week is giving trouble again" is a recipe for an accident. Were previous incidents overlooked because the results were, by good fortune, only trivial? The emphasis should shift from blaming the operator to removing opportunities for error or identifying weaknesses in the design and management systems.

When investigators are asked to look for underlying or root causes they sometimes call the causes they have found root causes. For example, a report said that the root cause of a flange leak was fitting the wrong size of gasket. But that was an immediate cause. To find the root cause we would have to ask if the right size of gasket was in stock and it not, why not; if the fitter who installed the gasket knew the possible consequences of fitting the wrong size and if not, why not; if there had been other cases of poor craftsmanship and if they were overlooked; and so on.

Most commentators on the disaster at Bhopal in 1984 missed the most important lesson that can be drawn from it: the material that leaked and killed over 2000 people was not a product or raw material but an intermediate. It was convenient to store it but not essential to do so and afterwards many companies did reduce their stocks of hazardous intermediates, often using them as they were made and replacing 50 or more tonnes in a tank by a few kilograms in a pipeline. For ten years since the explosion at Flixborough in 1974, the importance of keeping stocks of hazardous chemicals as low as possible had been advocated. Though reducing stocks saves money as well as increasing safety little had been done. If we can avoid hazards we can often design plants that are cheaper as well as safer.

The report on a serious explosion[3] that killed four men shows how easily underlying causes can be missed. The explosion occurred in a building where ethylene gas was processed at high pressure. A leak from a badly made joint was ignited by an unknown cause. After the explosion many changes were made to improve the standard of joint-making: better training, tools and inspection.

Poor joint-making and frequent leaks had been tolerated for a long time as all sources of ignition had been eliminated and so leaks could not ignite, or so it was believed. Though the plant was part of a large group the individual parts were independent so far as technology was concerned. The other plants in the group had never believed that leaks of flammable gas could not ignite. Experience had taught them that sources of ignition are liable to turn up, even though we do everything we can to remove known sources, and therefore strenuous efforts must be made to prevent leaks and good ventilation provided to disperse any that do occur. Unfortunately the managers of the plant involved in the explosion had hardly any technical contact with the other plants, though their sites adjoined. Handling flammable gases at high pressure was, they believed, a specialized technology and little could be learnt from those who

handled them at lower pressures. The plant was a monastery, a group of people isolating themselves from the outside world. The explosion blew down the monastery walls.

If the management of the plant where the explosion occurred had been less insular and more willing to compare experiences with other people in the group, or if the directors of the group had allowed the component parts less autonomy, the explosion might never have occurred. The senior managers of the plant and the group probably never realised or discussed the need for a change in policy. The leak was due to a badly made joint and so joints must be made correctly in future. No expense was spared to achieve this aim but the underlying weaknesses in the company organization and plant design were not recognized. However, some years later, during a recession, parts of the group were merged.

The causes listed in accident reports sometimes tell us more about the investigators' beliefs and background than about the accidents.

WE LIST HUMAN ERROR AS A CAUSE

Human error is far too vague a term to be useful. We should ask, "What sort of error?"

- Was it due to poor training or instructions? If so we need improve them and perhaps simplify the task.
- Was it due to a deliberate decision not to follow instructions or recognized good practice? If so, we need to explain the reasons for the instructions as we do not live in a society in which people will simply do what they are told. We should, if possible, simplify the task – if an incorrect method is easier than the correct one it is difficult to persuade everyone to use the correct method - and we should check from time to time that instructions are being followed.
- Was the task beyond the ability of the person asked to do it, perhaps beyond anyone's? If so, we need to redesign the task.
- Was it a slip or lapse of attention? If so, it no use telling people to be more a careful, we should remove opportunities for error by changing the design or method of working[4].

WE LIST CAUSES THAT DO NOT POINT TO EFFECTIVE ACTIONS

For example, a source of ignition is often listed as the cause of a fire or explosion. But, as we have just seen, it is impossible on the industrial scale to eliminate all sources of ignition with 100% certainty. While we try to remove as many as possible it is more important to prevent the formation of flammable mixtures.

For example, which is the more dangerous action on a plant that handles flammable liquids: to bring in a box of matches or to bring in a bucket? Many people would say that it is more dangerous to bring in the matches, but nobody would knowingly strike them in the presence of a leak and in a well-run plant leaks are small and infrequent. If a bucket is allowed in, however, it may be used for collecting drips or taking samples. A flammable mixture will be present above the surface of the liquid and may be ignited by a stray source of ignition. Of the two "causes" of the subsequent fire, the bucket is the easier to avoid.

I am not, of course, suggesting that we allowed unrestricted use of matches on our plants but I do suggest that we keep out open containers as thoroughly as we keep out matches.

Instead of listing causes we should list the actions needed to prevent a recurrence. This forces to people to ask themselves if and how the so-called cause can be prevented in future.

WE CHANGE PROCEDURES RATHER THAN DESIGNS

When making recommendation to prevent an accident our first choice should be to see if we can remove the hazard – the inherently safer approach. For example, could we use a non-flammable solvent instead of a flammable one? Even if is impossible on the existing plant we should note it for the future.

The second best choice is to control the hazard with protective equipment, preferably passive equipment as it does not have to be switched on. As a last (but frequent) resort we may have to depend on procedures. Thus, as a protection against fire, insulation (passive) is usually better than water spray turned on automatically (active), but that is usually better than water spray turned on by people (procedural). In some companies, however, the default action is to consider a change in procedures first, sometimes because it is cheaper but more often because it has become a custom and practice carried on unthinkingly. Figure 1 describes an example.

WE DO NOT LET OTHERS LEARN FROM OUR EXPERIENCE

Many companies restrict the circulation of incident reports as they do not want everyone, even everyone in the company, to know that they have blundered but this will not prevent the incident happening again. We should circulate the essential messages widely, in the company and elsewhere, so that others can learn from them, for several reasons:

- *Moral:* if we have information that might prevent another accident we have a duty to pass it on.
- *Pragmatic:* if we tell other organizations about our accidents they may tell us about theirs.
- *Economic:* we would like our competitors to spend as much as we do on safety.
- *The industry is one: every accident effects its reputation*. To misquote the well-known words of John Donne,

> *No plant is an Island, entire of itself; every plant is a piece of the Continent, a part of the main. Any plant's loss diminishes us, because we are involved in the Industry: and therefore never send to know for whom the Inquiry sitteth; it sitteth for thee.*

WE FORGET THE LESSONS LEARNED AND ALLOW THE ACCIDENT TO HAPPEN AGAIN

Even when we prepare a good report and circulate it widely, all too often it is read, filed and forgotten. Organizations have no memory. Only people have memories and after a few years they move on taking their memories with them. Procedures introduced after an accident are allowed to lapse and some years later the accident happens again, even on the plant where it happened before. If by good fortune the results of an accident are not serious, the lessons are forgotten even more quickly. This is the most serious of the missed opportunities and will be considered more fully than the others. Reference 5 describes many examples but here is a more recent one[6]:

During cold weather a water line froze and ruptured inside a building. Damage was fortunately not very serious. Three years later the same line froze and ruptured again. The heating in the building was not operating and the water line was near the door. The basement was flooded and two 15 m^3 tanks floated, reached the ceiling and pushed it up by 0.5 m. The incident occurred at a nuclear site. Can we blame the public for doubting the nuclear industry's ability to operate reactors safely when they let the same water line freeze and rupture twice?

The following actions can prevent the same accidents recurring so often:

- Include in every instruction, code and standard a note on the reasons for it and accounts of accidents that would not have occurred if the instruction etc had been followed. Once we forget the origins of our practices they become "cut flowers"; severed from their roots they wither and die.
- Never remove equipment before we know why it was installed. Never abandon a procedure before we know why it was adopted.
- Describe old accidents as well as recent ones, other companies' accidents as well as our own, in safety bulletins and discuss them at safety meetings.
- Follow up at regular intervals to see that the recommendations made after accidents are being followed, in design as well as operations.
- Remember that the first step down the road to an accident occurs when someone turns a blind eye to a missing blind.
- Include important accidents of the past in the training of undergraduates and company employees.
- Keep a folder of old accident reports in every control room. It should be compulsory reading for new employees and others should look through it from time to time.
- Read more books, which tell us what is old as well as magazines that tell us what is new.
- We cannot stop downsizing but we can make sure that employees at all levels have adequate knowledge and experience. A business historian has described excessive downsizing as producing the corporate equivalent of Alzheimer's disease[7].
- Devise better retrieval systems so that we can find, more easily than at present, details of past accidents, in our own and other companies, and the recommendations made afterwards. We need systems in which the computer will automatically draw our attention to information that is relevant to what we are typing (or reading), as described below.

Of course, everyone forgets the past. An historian of football found that fans would condense the first hundred years of their team's history into two sentences and then describe the last few seasons in painstaking detail. But engineers' poor memories have more serious results.

WEAKNESSES IN SAFETY TRAINING

There is something seriously wrong with our safety education when so many accidents repeat themselves so often. The first weakness is that ***it is often too theoretical***. It starts with principles, codes and standards. It tells us what we should do and why we should do it and warns us that we may have accidents if we do not follow the advice. If anyone is still reading or listening it may then go on the describe some of the accidents.

We should start by describing accidents and draw the lessons from them, for two reasons. First, accidents grab our attention and make us read on, or sit up and listen. Suppose an article describes a management system for the control of plant and process modifications. We probably glance at it and put it aside to read later, and you know what that means. If it is a talk we may yawn and think, "Another management system designed by the safety department that the people on the plant won't follow once the novelty wears off". In contrast, if someone describes accidents caused by modifications made without sufficient thought we are more likely to read on or listen and consider how we might prevent them in the plants under our control.

We remember stories about accidents far better than we remember naked advice. We all remember the stories about Adam and Eve and Noah's Ark far better than all the "dos and don'ts" in the Bible.

The second reason why we should start with accident reports is that the accident is the important bit: it tells us what actually happened. We may not agree with the author's recommendations but we would be foolish to ignore the event. If the accident could happen on our plant we know we should take steps to prevent it, though not always those that the report recommends.

A second weakness with our safety training is that it usually consists of ***talking to people rather than discussing with them***. Instead of describing an accident and the recommendations made afterwards, outline the story and let the audience question you to find out the rest of the facts, the facts that they think are important and that they want to know. Then let them say what ***they think*** ought to be done to prevent it happening again. More will be remembered and the audience will be more committed than if they were merely told what to do.

Jared Diamond writes, "Contrary to popular assumptions cherished by modern literate societies, I suspect that we still learn best in the way we did during most of out evolutionary history – not by reading but through direct experience… For us the lessons that really sink in aren't always those learned from books, despite what historians and poets would like us to believe. Instead, we absorb most deeply the lessons based on our personal experience, as everybody did 5400 years ago[8]."

Once someone has blown up a plant they rarely do so again, at least not in the same way. But when he or she leaves the successor lacks the experience. Discussing accidents is not as effective a learning experience as letting them happen but it is the best simulation available and is a lot better than reading a report or listening to a talk.

WHICH REPORTS SHOULD BE DISCUSSED?

We should choose for discussion accidents that bring out important messages such as the need for permits-to-work, the control of modifications, inherently safer designs and so on. In addition, we should:

- If possible, discuss accidents that occurred locally. The audience cannot then say, "We wouldn't do anything as stupid as the people on that plant".
- Draw attention to the missed opportunities described above, in particular to the fact that many people have opportunities to prevent accidents, starting with the chemist who chooses the process, through the engineers who design the plant and ending with the operator who closed the wrong valve. Operators often fall into the traps that others have laid for them and are the people with least responsibility.
- Choose simple accidents. Many engineers are fascinated by complex stories in which someone had to puzzle out some unusual causes. Most accidents are not like that but have quite simple causes. After a fire, one company gave a lot of publicity to an unusual source of ignition and successfully distracted attention from the poor design and management that allowed four tons of hot hydrocarbon to leak out of the plant. No one asked why it leaked or how the company was going to prevent it leaking again.

Undergraduate training should include discussion of some accidents, chosen because they illustrate important safety principles such as the need for inherently safer design, the identification and assessment of hazards, the science of fires and explosions and the need to

look below the immediate technical causes for ways of avoiding the hazard and for weaknesses in the management system. Discussion, as already mentioned, is more effective than lecturing but more time-consuming.

If universities do not provide this sort of training industry should provide it. In any case, new recruits will need training on the specific hazards of the industry.

SAFETY DATABASES SHOULD BE ACTIVE AND FUZZY

Accident databases should, in theory, keep the memory of past incidents alive and prevent repetitions, but they have been used less than expected. A major reason is that we look in a database only when we suspect that there might be a hazard. If we don't suspect there may be a hazard we don't look.

In conventional searching the computer is passive and the user is active. The user has to ask the database if there is any information on, say, accidents involving particular substances, operations or equipment. The user has to suspect that there may be a hazard or he or she will not look. We need a system in which the user is passive and the computer is active. With such a system, if someone is using a word processor, a design program or a Hazop recording program and types "X" (or perhaps even makes a diary entry that there is going to be a meeting on X) the computer will signal that the database contains information on this substance, subject or equipment. A click of the mouse will then display the data. As I type these words the spellcheck and grammar check programs are running in the background drawing my attention to my (frequent) spelling and grammar errors. In a similar way, a safety database could draw attention to any subject on which it has data. Filters could prevent it repeatedly referring to the same hazard.

A program of this type has been developed for medical use. Without the doctor taking any action the program reviews the information on symptoms, treatment, diagnosis etc already entered for other purposes and suggests treatments that the doctor may have overlooked or not be aware of[9].

When we are aware that there is or may be a hazard and carry out conventional searching it is hindered by another weakness: it is hit or miss. We either get a "hit" or we don't. Suppose we are looking in a safety database to see if there are any reports on accidents involving the transport of sulphuric acid. Most search engines will display them or tell us there are none. A "fuzzy" search engine will offer us reports on the transport of other minerals acids or perhaps on the storage of sulphuric acid. This is done by arranging keywords in a sort of family tree. If the there are no reports on the keyword, the system will offer reports on its parents or siblings.

There is ample power in modern computers to do all that I suggest. We just need someone willing to develop the software. It will be more difficult to consolidate various databases into one and to make the program compatible with all the various word processor, design, Hazop and control programs in use.

At Loughborough we have demonstrated the feasibility of fuzzy searching and carried out some work on active computing[10,11,12,13].

CULTURAL AND PSYCHOLOGICAL BLOCKS

Perhaps there are cultural and psychological blocks, which encourage us to forget the lessons of the past.

- We live in a society that values the new more the old, probably the first society to do so. *Old* used to imply enduring value, whether applied to an article, a practice or knowledge.

Anything old had to be good to have lasted so long. Now it suggests obsolete or at least obsolescent.

- We find it difficult to change old beliefs and ways of thinking. In the 19th century people found it difficult to accept Darwinism because they has been brought up to believe in the literal truth of the Bible.
- A psychological block is that life is easier to bear if we can forget the errors we have made in the past. Perhaps we are programmed to do so.

The first step toward overcoming these blocks is to realise that they exist and that engineering requires a different approach. "It is the success of engineering which holds back the growth of engineering knowledge, and its failures which provide the seeds for its future development[14]."

CAN THE LAW HELP?

The Health and Safety Commission have issued *Discussion* and *Consultative Documents*[15], which propose that companies and other organisations should be required by law to investigate accidents that occur on their premises. Will this reduce accidents?

It could but whether or not it will depends on a number of factors:

- Companies could be obliged to follow the follow the first five "opportunities" listed in this paper, but the requirement will be effective only if the Health and Safety Executive (HSE) reads a significant proportion of the reports to see if the underlying causes are found, if suitable recommendations are made and if they are carried out. Will they have the resources to do so? It is easy to tell companies what they should do. It is much more difficult to check that they are doing it thoroughly and not just going through the motions to satisfy the letter of the law.
- Will the law state that its purpose it to investigate accidents ***so that action can be taken to prevent them happening again, not to attribute blame?*** Industry is coming to realise that many people could have prevented almost every accident but the press and politicians seem more interested in finding someone to blame. (On 18 October 2000, the day after the Hatfield train crash, the *Daily Telegraph*'s front page banner headline was "Who is to blame this time?") When discussing crimes they look for the underlying causes such as poverty, upbringing, ill-treatment and peer-group pressure. In contrast, when discussing industrial accidents, instead of looking for the changes in designs and procedures that could prevent them, they assume they are due to managers putting profit before safety. If the law is interpreted in this spirit it will divert attention away from effective action and will do more harm than good.

  Remember the words of the report on the tip collapse at Aberfan in 1966 which killed 144 people, most of then children[16]: "Not villains, but decent men, led astray by foolishness or by ignorance or by both in combination, are responsible for what happened at Aberfan". The problem is not how to stop bad people hurting other people but how to stop good people hurting other people.

  To quote John Humphreys, "Responsibility has been redefined to include being seen to do something, anything, in response to transient public sentiment often generated by television images, rather than coolly assessing what are realistically the best options"[17].

- Will the HSE be able to insist that the reports are published, anonymously if companies wish, so that others can learn from them?
- Most important of all, there is no mention in the HSE *Documents* of the need to see that the lessons of the past are remembered or the methods by which this can be done. Yet unless the information in accident reports is spread and remembered the work involved in the investigation is largely wasted. At best it produces only a local and temporary improvement.

Afterthought

I remember the first time I rode a public bus… I vividly recall the sensation of seeing familiar sights from a new perspective. My seat on the bus was several feet higher than my usual position in the back seat of the family car. I could see over fences, into yards that been hidden before, over the side of the bridge to the river below. My world had expanded. –

Ann Baldwin[18]

We need to look over fences and see the many opportunities we have to learn from accidents.

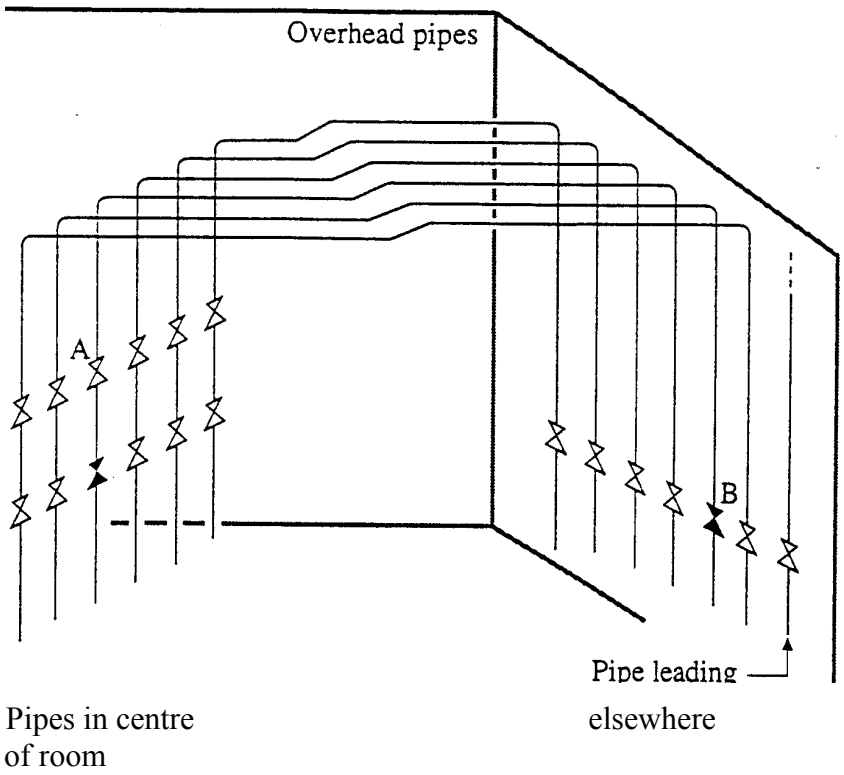

Figure 1 The fine adjustment valve A had to be changed. The operator closed the valve below it. To complete the isolation, he intended to close the valve on the other side of the room in the pipe leading to valve A. He overlooked the double bends overhead and closed valve B, the one opposite valve A. Both of the valves that were closed were the third from the ends of their rows. Note that the bends in the overhead pipes are in the horizontal plane. When valve A was unbolted the pressure of the gas in the line caused the topwork to fly off and hit the wall.

The report on the incident recommended various changes in procedures. Colour coding of the pipes or valves would have been more effective but was not considered. A common failing is to look for changes to procedures first; to consider changes in design only when changes in procedure are not possible; and to consider ways of removing the hazard rather than controlling it only as a last resort.

1. McQuaid, J., 2001, Review of *By Accident – A Life Preventing them in Industry*, *Process Safety & Environmental Protection*, 79B: 58.

2. Sanders, R., 1999, *Chemical Process Safety – Learning from Case Histories,* Butterworth-Heinemann, Boston, MA, Chapter 1.

3. Kletz, T. A., 2001, *Learning from Accidents*, 3rd edition, Butterworth-Heinemann, Oxford, UK, Chapter 4.

4. Kletz, T. A., 2001, *An Engineer's View of Human Error*, 3rd edition, Institution of Chemical Engineers, Rugby UK.

5. Kletz, T. A., 1993, *Lessons from Disaster - How Organisations have No Memory and Accidents Recur*, Institution of Chemical Engineers, Rugby UK.

6. Anon., 2000, Freeze protection problems cause damage and loss of fire protection, *Operating Experience Summary,* No 2000-3, Office of Nuclear and Facility Safety, US Dept. of Energy, Washington, DC.

7. Kransdorf, A., 1996, *The Guardian,* 12 October, p. 19.

8. Diamond, J., 2000, Threescore and ten, *Natural History*, Dec 2000/Jan 2001, p. 24.

9. Anstead, M., 1999, More needles, less haystack, *Daily Telegraph Appointments Supplement*, 18 November, p. 1.

10. Chung, P. W. H. and Jefferson, M., 1988, A fuzzy approach to accessing accident databases, *Applied Intelligence*, 9: 129.

11. Iliffe, R. E., Chung, P. W. H., and Kletz, T. A., 1999, More Effective Permit-to-Work Systems, *Proc Safety Env Protection*, 77B: 69.

12. Iliffe, R. E., Chung, P. W. H., and Kletz, T. A., 1998, Hierarchical Indexing, Some lessons from Indexing Incident Databases, *International Seminar on Accident Databases as a Management Tool*, Antwerp, Belgium, November.

13. Iliffe, R. E., Chung, P. W. H., Kletz, T. A., and Preston, M. L., 2000, The Application of Active Databases to the Problems of Human Error in Industry, *J Loss Prev Process Industries*, 13:19.

14. Blockley, D. I. and Henderson, J. R., 1980, *Proc Inst Civ Eng*, Part 1, 68:719.

15. Health and Safety Commission, 1998, *A new duty to investigate accidents, Discussion Document,* HSE Books, Sudbury, UK. A *Consultative Document* with the same title was published in 2001.

16 1966, *Report of the Tribunal appointed to inquire into the disaster at Aberfan on October 21st 1966*, HMSO, London, paragraph 47.

17. Humphrys, J., 1999, *Devil's Advocate,* Hutchison, London, UK, page 63.

18. Baldwin, A. D., 1995, Letter: *Biblical Archaeology Review*, May/June, p. 50.