Safety: too important a matter to be left to the engineers?

Professor Richard Booth

35th Anniversary of Inaugural lecture - 22 February 1979

Introductory note

11 February 2014

Readers might best choose to read the first three paragraphs of the Introductory Note then read the lecture. After reading the lecture some might be interested in following up the story to 2014 - the main focus of the rest of this Introductory Note.

It is a duty of newly-appointed professors to present an inaugural lecture. These are challenging occasions. The lecture must be accessible to a lay audience but also demonstrate that the appointment board has selected a candidate with a scholarly mien and appropriate gravitas.

My additional challenge was that my title aroused strong criticism from professorial engineering colleagues, and the lecture involved a detailed critique of the Flixborough Explosion Inquiry Report. Aston's Vice-Chancellor (Dr JA Pope) was Vice Chair of the Inquiry[1].

I re-read my lecture when preparing my obituary for Dr Kletz last December [link]. I realized first that the 35th anniversary was impending; secondly that it was topical in 2014 as the 100th Anniversary of the outbreak of the Great War approaches, and thirdly that the lecture raised issues that are now axioms of safety management.

The genesis of the lecture and what has happened since – how has the lecture stood the test of time – and what happened to the recommendations?

I joined Aston as a mechanical engineer. My first subjects were structural integrity and machinery guarding and these formed the technical foundation for the lecture. I knew little about the 'soft sciences'; their application to safety at work, and the research evidence. All this I learnt from my colleagues. The non-technical themes of the lecture reflected our evolving views at Aston generally and my particular interests, notably risk taking and defeating machinery guards.

The lecture highlighted the following issues that were arguably at the cutting edge in 1979:

- The concept that human failures involved both unintended errors and rule violations (then 'risk taking') was only perceived as crucial some years later;

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[1] Dr Pope tactfully absented himself from the lecture, but generously congratulated me the following morning. Incidentally my colleague Professor Andrew faced a far greater challenge. He was obliged to present his lecture in Dutch (at Delft University) well-before he had fully commanded the language.

- The importance of risk assessment (then 'procedures to identify and control dangers') was emphasised; enshrined in legislation much later;
- The need for accident investigators to pursue the underlying and root causes (then 'preconditions');
- The phrase 'technical, behavioural and procedural aspects of safety' may not have been in common usage at the time. Together with Law and Occupational Health they (with variations in exact wording) were from the outset the five modules of Aston courses and carried through into NEBOSH;
- The following quotation continues to be apposite "I suspect that some practitioners in the risk equation business become so intoxicated by the elegance of their mathematical analysis that they fail to recognise the vast potential for errors in their basic assumptions and in their raw data".

My theme was that "safety is too important a matter to be left to any key professional group, whether engineers, doctors, chemists, psychologists, lawyers or accountants." In 1979 these professional groups thought themselves as having 'ownership' of safety in their domains. Many still do. But in 2014 safety practitioners should be added to the list. If I was to give the lecture again it would have the title "Safety: too important a matter to be left to the safety professionals". In 1979 safety professionals were an endangered species. Now they play a dominant role in risk decision-making and many perceive that their domain is the whole field, encompassing ownership of legislation, management systems, human factors, tolerability of risk, as well as technical controls. And case studies of some contemporary accidents and disasters could have pointed to the shortcomings of safety practitioners (some in regulatory bodies) in much the same way as I castigated engineers 35 years ago.

The presumptions I made that First World War generals lacked strategic insights and were incompetent has been challenged by modern historians (although the tensions between the generals and politicians are historical fact).

On their terms my basic analogy to the First World War is wrong. The arguments are that a long period of attritional warfare on the primary battlefield is now accepted as inevitable before a final victory was to be won[2]. The resources devoted to 'side shows' impeded the main effort on the Western Front. The learning curve of strategic and tactical methods to break through 'impregnable' trench lines could barely have been more rapid, and by 1917 the rapidly-formed citizen British Empire army was just the match of the German army, and by August 1918 by far the most effective army on the Western Front.

The 'interference' of the politicians was, it is now argued, often counter-productive, and prolonged the duration of the War. So 'war: too important a matter to the generals', the axiom that underpinned the lecture has, paradoxically been the part that has least well withstood the test of time. But while the military analogy is now challenged by military historians, the

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2 The Second World War was won by a prolonged attritional battles on the Eastern Front and in bombing campaigns with vastly greater casualties than in the First War. During the Cold War the West, for political reasons, down-played the Soviet Union's dominant contribution to final victory. I have added a footnote in the main text developing some of these points.

argument that safety should not be dominated by any professional group is if anything more apposite today.

I criticised then recent major accident inquiry reports for complacency in 1979. Now, taking just the petro-chemical industry, the findings of inquiries are at least as austere as those in the late 19th/early 20th Century. And hindsight bias exaggerates in varying degrees the culpability of those involved.

I am glad ***now*** that I stated "the sharp and sometimes sarcastic criticisms … in Courts of Inquiry some 50 to 100 years ago[3] are unfortunate" (and also regrettable). For at that time I was all in the favour of sharpness and sarcasm, and the comment was there for tact. The prosecution case summary following the Buncefield explosion in 2005, replete with sarcasm, is a return to Victorian values.

The conclusion of the talk was that engineers should receive training. While the Engineering Council for 25 years has required safety to be incorporated in engineering courses, the uptake has been disappointing. I now know that invoking 'training' as the panacea solution to deep-rooted problems is usually naïve.

It is for others to judge whether the lecture was a contribution to the safety debate many years ago and to consider its current relevance. The main thing is that several key concepts that were in their infancy in 1979 are now central to safety management. Perhaps more important is the case-study approach, where general principles emerge from a small number of examples, is appropriate for a lay audience and to offer some pretence at erudition in an inaugural lecture.

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3 The are other Inquiry reports over the period. The one I now know well is that for the R101 airship disaster in 1930. The Report was muted in its criticisms of distinguished engineers who were risk-taking incompetents.

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Inaugural lecture given on 22 February 1979

Some of the illustrations are new, as are the captions. Three of the original illustrations are unavailable. The footnotes are all new as are some of the section headings

1 Introduction

The engineering profession has played, and continues to play, a vital role in preventing accidents at work. But many fatal and serious accidents which still occur are attributable, in part, to errors by engineers which could and should have been avoided. I am therefore asking the provocative but I believe very pertinent question – safety: too important a matter to be left to the engineers? I must stress that my choice of subject is not based on any belief that engineers are more prone to mistakes or more open to criticism than other professional groups. My theme is a special case of the general argument that safety is too important a matter to be left to any key professional group, whether engineers, doctors, chemists, psychologists, lawyers or accountants.

The title of the lecture and the philosophy which underlies it is based on Talleyrand's dictum:

> *'War is much too serious a thing to be left to military men'*

As an aside Talleyrand, see Figure 1, was variously a bishop before the French Revolution, Napoleon's Foreign Secretary, and, after the Bourbon restoration, Ambassador to Great Britain. He deserves attention as a major statesman and also for his astuteness in retaining favour with three very different regimes.

Figure 1: Charles-Maurice de Talleyrand-Périgord (1754-1838)

Figure 2: Aristide Briand (1862 – 1932) Prime Minister of France 11 times, including 1915 – 1917. Nobel Peace Prize winner 1926. He was replaced by Clemenceau after the French Army mutinied in 1917

Figure 3: David Lloyd George (1863 – 1945) Prime Minister 1916 – 1922 (shown here with Winston Churchill (1874 – 1965) in 1910). In contrast to Churchill, Lloyd George lacked physical courage and moral scruples. But his sobriquet "the man who won the war" has validity. He invented the working breakfast

Briand (Figure 2), Prime Minister of France during part of the Great War, quoted Talleyrand's dictum to Lloyd-George (Figure 3) during one of their encounters with the Allied High Command. In fact he said *"War is too important a matter to be left to the Generals"*.

The politicians had little confidence in the military leaders; their view was widely shared at the Front.

Figure 4: The Western Front: the tragedy of the Great War 1914 -1918. Immediately before the 1917 mutiny, piolus advanced to the front murmuring 'baaa' – lambs being led to the slaughter. But documentary evidence now shows that British Commonwealth troops maintained robust morale even during the nightmare of the Somme. French morale remained good even during Verdun in 1916. They mutinied when required to advance in the worst planned offensive of the War led by General Nivelle. Lloyd George strongly supported the offensive and conspired to place FM Haig under Nivelle

The politicians such as Lloyd-George and Briand believed that some generals lacked competence in the basic technicalities of their profession and in the organisational skills necessary to administer large formations. The politicians found it difficult to sack or reprimand incompetent generals in face of opposition from the High Command.

The generals themselves sometimes condoned the actions of incompetent colleagues drawn from the same close-knit professional and social circle. Moreover the politicians felt that many generals were out of touch with the realities of front-line fighting conditions, and were slow to respond to new developments which could reduce casualties. Above all they realised that many decisions perceived by the generals as being purely 'military' decisions were in fact 'politico-military' decisions which required a breadth of training and experience which the generals, they believed, conspicuously lacked.

In turn the generals bitterly resented the attempted intrusions on their sovereignty by the politicians who they derided as 'amateur strategists'. The generals may have been quite right about the 'amateurish' politicians. But I believe that the generals were wrong in their contention that all advice and instructions from without should be rejected on principle[4].

I have referred to the devastation and tragedy of war, a typical scene is shown in Figure 4 above. The following photographs draw attention to the fact that, for the participants, the consequences of occupational accidents are just as final.

2 Accidents at work

The crane driver was killed as a consequence of the collapse of a tower crane on a hospital during construction, see Figure 5. The immediate cause of the accident was the fatigue failure of the weld-fabricated slewing ring bolts.

Figure 5: Tower crane collapse

[4] Contemporary (2013) historians now take a much more sanguine view of the competence of the British Generals during the War. The devastating German Offensive in March 1918 succeeded largely because Lloyd George held back reinforcements at home. But from August 1918 the British Army was the best led and most effective Army on the Western Front. The War was in fact won in 1918 by the British Canadians and Australians aided by armoured vehicles. The French morale was still brittle and the American contribution was insignificant. American generals repeated the mistakes of their Allied co-belligerents in 1915-17. But in the Wars of the 20th Century German generalship, and the bravery and initiative of their troops, were in a class of their own. But Churchill's advocacy of tanks (if not as he claimed their inventor) and his indomitable courage in WW2 prevented the Nazis dominating the World.

A boiler exploded as a result of a fall in the water level below the furnace crown, see Figure 6. The boiler attendant, who was in fact killed in this accident had closed two valves, but had forgotten to open them again before restarting the boiler. All four low-water level safety devices were so interdependent that they were all rendered inoperative by the man's mistake. That is to say the water-feed pump control was rendered inoperative, so were the low water alarms, so were the fuel oil cut-offs, and so were the sight glasses.

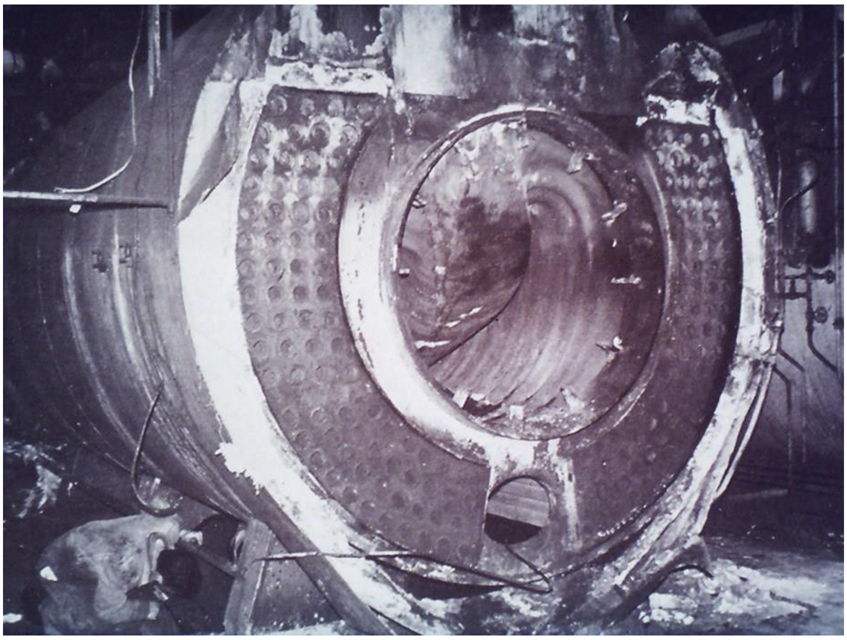

Figure 6: Boiler explosion (plastic deformation and rupture as a result of overheating)

A poor young man of 18, employed as a labourer in a quarry for only two days, was killed when he was trapped in the conveyor tension rollers after he (or others) had improperly removed the guard while the conveyor was in motion, see Figure 7. But it was necessary to removed the guard in order to clean, to lubricate, and to adjust the conveyor pulley[5].

Figure 7: Quarry conveyor fatal accident

[5] I am indebted to the late John Kinsey (MSc Aston 1974 –75) for this case.

The data given in Table 1 reproduced from Lord Rothschild's Richard Dimbleby Memorial Lecture suggest that the risk of being killed in a quarry is greater than the risk of being killed in any other occupation in the United Kingdom. In 1974, the year being considered here, one in every five fatalities in a quarry involved men being trapped in conveyors.

Table 1: Risk of being killed in certain UK industries, 1974

Quarrying	1 in 3100
Underground coal mining	1 in 5300
Chemical industries	1 in 5800
Farming	1 in 9200
Food, drink and tobacco	1 in 21,700
Clothing and footwear	1 in 500,000

Quoted from Lord Rothschild's Richard Dimbleby Memorial Lecture, November 1978.

The question of the accuracy of risk figures such as those given in Table 1, and the acceptability of risk, has been widely debated recently, and I do not want to pursue the matter in detail. I would, however, like to make three comments.

First, the debate on the acceptability of risk has concentrated on the dangers of major accidents which may affect the public. Too little attention has been paid in the debate to the high risk to some individuals, working for example, in quarries.

Secondly, there will always be an irreconcilable difference between the perception of what is an acceptable risk by those who are exposed directly to the danger and those who are not.

Thirdly, I suspect that some practitioners in the risk equation business become so intoxicated by the elegance of their mathematical analysis that they fail to recognise the vast potential for errors in their basic assumptions and in their raw data.

It would be absurd to suggest that the risks that work people are exposed to today are in any way comparable to the fatality rates in war time. But the analogy between the role of engineers with respect to safety at work and role of military men is nonetheless apposite. Both groups have a duty to find the best ways of reducing casualties, while at the same time achieving other highly laudable, but conflicting, objectives. Moreover, the arguments which I have described between the soldiers and the politicians are reflected in many contemporary debates concerning safety at work.

For example, in a non-engineering context, The 'Observer' newspaper in an editorial which related to a recent and distressing laboratory accident stated:

> *'The overwhelming evidence from the… Report is of a group of specialists, closely linked socially and professionally, unable or unwilling to criticise a colleague.'*

The Observer, 7 January 1979

And on the question of outside interference, the Institution of Nuclear Engineers have issued a press statement which contained the following:

> *'In practice, safety assessment is usually a matter of expert judgement, as when the passengers in an aircraft prefer the pilot's judgement to the consensus of their own uninformed opinions. Eminence in other fields is seldom an acceptable substitute for specialised experience in matters of safety.'*

Extract from a Statement by the Institution of Nuclear Engineers, November 1978

Incidentally, quite apart from the firm rejection of most external advice implicit in the statement, I personally feel that the 'airline pilot' analogy is false and misleading. It is bizarre to infer that 'eminent outsiders' should not be listened to because they would wish to tamper with the controls in the cockpit or in a nuclear power station control room during a complex start-up sequence. Rather the outsiders might well, for example, be able to offer some very pertinent advice about start-up procedures in general and about human reliability in high-stress situations[6].

3 A framework for the study of danger

Accidents at work happen in diverse circumstances. Each accident involves a combination of many factors. There is thus a need to clear the ground to provide a framework within which I can examine in detail the role of the engineer in the prevention of occupational accidents and the argument that engineers require, from time to time, advice and restraint from outside their ranks.

The immediate causes of an injury or fatality are sometimes associated with shortcomings in the physical working conditions and systems of work, sometimes with errors or risk-taking on the part of the work people at risk or their workmates. Examples of all these shortcomings were evident in my brief accident narratives to which I have referred already. But the immediate causes of accidents are merely the symptoms of more underlying problems. Efforts to prevent the immediate causes of each accident – a particular set of errors or omissions – only ensures the prevention of one particular accident – the last one. Such efforts will do little to prevent the next.

It is essential that we identify and attack the underlying reasons for these accidents. In terms of the work of engineers that are, irrespective of the diversity of the immediate causes, a small number of underlying reasons, or 'pre-conditions', for accidents at work:

I should mention that the list of 'pre-conditions' shown in Table 2 is not intended to be mutually exclusive. An incident generally involves a combination of these items.

The first pre-condition relates to engineers who:

> lack **technical** competency in their basic engineering knowledge, for example the engineer who was responsible for the weld-fabricated bolts on the tower crane.

It is quite possible, of course, that in this and other cases the work of the professional engineers was being done by unqualified engineers and the problem becomes one of an organisational shortcoming which I will discuss later.

Table 2: Pre-conditions for engineering accidents

1. Engineers who:
   lack **technical** competency
   lack an understanding of the foreseeable behaviour of people at work.
   - human errors
   - 'risk-taking'
2. Organisational shortcomings:

[6] In the Kegworth air disaster in 1989, the pilots believed that the port engine was on fire. Passengers and cabin crew could see from their widows that it was the starboard engine on fire.

- absence of procedures to **identify** and **control** dangers
- breakdown of procedures in the face of, for example, pressures for production.

But more important is the lack of understanding by some engineers of the foreseeable behaviour of people at work. The fact that people make errors for example, the mistake the boiler attendant made. Or that people at work take risks, for example, the labourer's wilful removal of the guard.

I am not suggesting that blame does not reside in large measure with the boiler man and with the labourer. What I am saying is – that both these accidents would have been prevented if the engineers responsible for the design and layout of that machinery had recognised in advance the reasonably foreseeable behaviour of people operating the equipment.

The second pre-condition involves shortcomings in the organisation of the engineering function:

> accidents occur because of the absence of procedures, systematic procedures, to **identify** the dangers at work, and to **control** these dangers.

Later I will be referring to the accident at Markham Colliery as an instance of this problem. Sometimes the issue concerns a breakdown of the procedures in the face of pressures for production, pressures to get the plant on stream again, pressure to get the job done. I have chosen the Flixborough Disaster as my example of that situation.

Section 2 of the Health and Safety at Work etc. Act, 1974 specifically places a legal obligation on employers to employ trained and competent staff and to create and maintain safety procedures and arrangements which are capable of identifying and controlling dangers. The two most recent reports of the Chief Inspector of Factories drew attention to the poor quality of the safety organisational arrangements in much of British industry. My experience is that, with the exception of certain firms, for example in the chemical industry, comprehensive engineering procedures to identify machinery guarding and plant reliability problems, are the exception not the rule.

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4 Case studies – machinery safety

It is now an appropriate juncture to review certain accidents in detail in order to illustrate the list of pre-conditions and to draw attention to the importance and the implications underlying the causes of these engineering accidents. I am most grateful to certain ex-students from the Department for permission to discuss a number of these examples.

Acrylic Fibre Accident *(illustrations not available)*

Machines for processing acrylic fibres are used in the man-made fibre industry. Individual fibres are stretched around a series of rollers. Quite often a fibre breaks and forms a lap around one of the rollers. The duty of the machine operator was to cut the lap with a knife, but in order to do so he was obliged to approach close to the in-running traps. An operator was killed between roller and fibre when he was cutting a lap.

I suggest that it was reasonably foreseeable that, from time to time, operators would make errors at the crucial stage of their close approach to the trapping area. This type of accident is not an isolated example. The lesson from this and related accidents is that engineering designers should be required to have a greater knowledge of the limitations of human reliability so that they, too, could foresee what is quite predictable by people whose full-time job is accident prevention and accident investigation. In this case a lot of technical ingenuity was required to modify the machine so that the laps were cut automatically, and close approach was no longer required.

A related issue concerns the presumption by some engineers that people will not *take risks* in working situations where immediate benefits will accrue from taking risks.

Liverpool & Manchester Railway – the Rainhill Trails

As far back as 1829 the Directors of the Liverpool and Manchester Railway Company were alive to this issue:

> 'Stipulations and conditions on which the Directors of the Liverpool and Manchester Railway offer a premium of £500 for the most improved Locomotive Engine'. April 1829.
>
> '3d There must be two Safety Valves, *one of which must be out of reach or control of the Engine-man,* and neither of which must be fastened down while the Engine is working.'

The stipulation after the early years of the Liverpool and Manchester Railway was never properly heeded. A series of boiler explosions, the most famous being at Lickie Hill in 1840, occurred because the actual safety valves employed were within easy reach of the engine driver and easy to screw or weigh down. The engine driver derived benefits from defeating the safety devices because the locomotives were somewhat under powered. It is only a small exaggeration to say that the trains could only reach their destinations on time if the driver broke the safety rules. It was not until 1858 with the design of the 'Ramsbottom' valve, which was very difficult to defeat, that this problem was solved in principle. But some locomotive chief engineers did not adopts the improved valve for a further forty years.

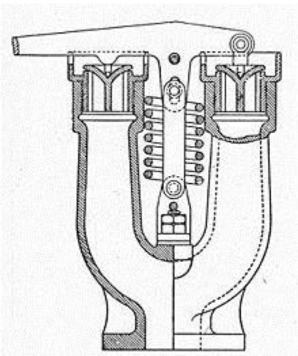

Figure 8: The Ramsbottom pressure relief valve 1858. In 1979 I had only read about the design – this is a new figure – at first sight it seems far from tamper-proof. It would seem easy to attach a weight on the top-left of the lever

The Rainhill trials and the prize of £500 was in fact won by the 'Rocket' locomotive, jointly entered by my kinsman Henry Booth, who invented the multi-tubular boiler, and the Stevensons. Henry Booth's involvement has not been properly acknowledge. I apologise for using the occasion of my Inaugural Lecture for correcting a serious historical omission!

Figure 9: **A replica of the Rocket (1829) in the National Rail Museum, York**

Figure 10: **Bust of Henry Booth, with a portrait of his Father Thomas behind.** Thomas Booth lived in Rodney St, Liverpool almost next door to WE Gladstone's childhood home

Figure 12: **Locomotives on the L&MR in 1831.** Once Robert Stevenson had mastered the technology, he was able to increase dramatically the number of tubes, and thus improve efficiency, but still not enough for the steepest inclines

It is sad to record that despite vast advances in engineering design in the last 150 years, the use of safety devices which are easy to defeat continues to be widespread. (It only matters, of course, if, in the eyes of the user of the machine there are 'good' reasons for defeating it).

Dough divider accident[7] *(illustrations of divider not available)*

Dough dividers are used for separating the dough for individual loaves of bread. Dough is fed into the hopper at the top of the machine.

Dough which has broken through the seals and if not cleaned out regularly the dough builds up and will rapidly clog the machine. There are a large number of dangerous parts of machinery which can cause serious injury to the operator. There is usually pressure on the operator to clean out the machine while it is in motion and hence dangerous. Otherwise the workforce has to work a longer shift to make the quota of bread. The system in bakeries is that the quota must be made before anybody can go home. Moreover when this machine is out of operation the ovens tend to overheat so the next few loaves are burnt. So that there are very good reasons for the operator of this machine to defeat the interlocked guard, which is a type of guard which, when removed, should prevent the machine from operating. But the interlocked guard can be defeated with fatuous ease with the use of a piece of wood which can be seen simply holding down the plunger-type limit switch and thus facilitating the defeating of the safety device. Fifty per cent of all preventable machinery accidents at work are attributable to the defeating or misuse of safety devices. A much better interlock device, see Figure 13, involves a positively operated limit switch. Note the welded joint between cam and hinge. This makes the device far more difficult to defeat.

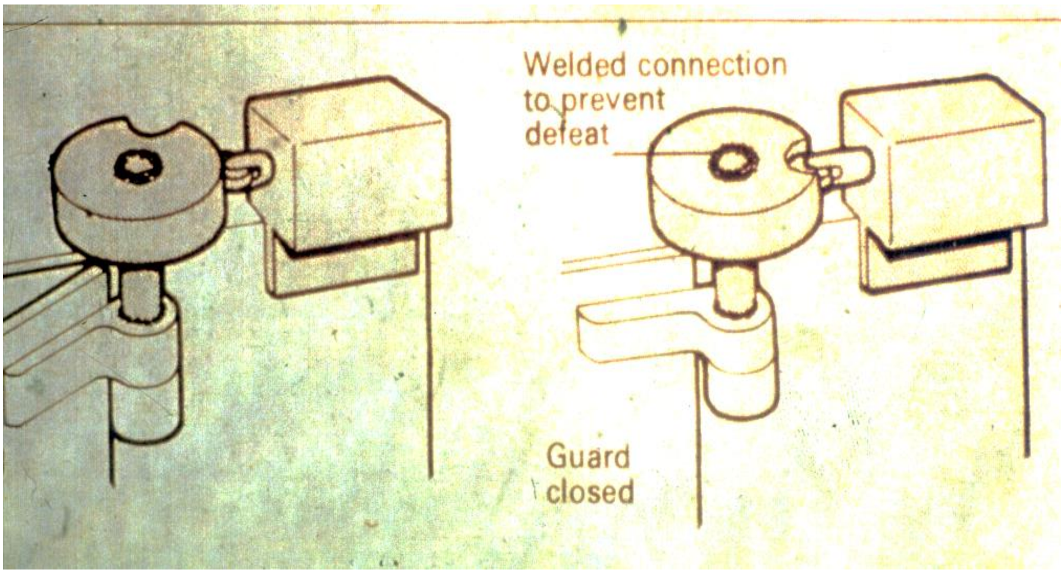

Figure 13: 'Normally closed' (positive operation) electrical limit switch

A wealth of knowledge exists about the appropriate design of safety devices which are difficult to misuse or defeat in relation to the benefits which accrue from defeating them. But this knowledge tends to be concentrated within the Health and Safety Executive, among safety advisers in industry, and within specialist guard manufacturers. I am less than certain that the majority of

7 I am indebted to Phil Hughes and Jim Stranks (both MSc Aston 1974–75) for this case study, and to the former for the 'acrylic fibre' case above. I apologise to them both for not acknowledging them at the time. Perhaps this is the reason why they did not acknowledge subsequently their reproduction of my course notes in their best selling text books.

engineering designers either appreciate the need for tamper-proof safety devices or have an appropriate knowledge of the detailed design of such mechanisms.

As I have said already, because the immediate cause of these accidents involves improper use by the user of the machine, the engineering designer is not directly vulnerable to criticism, despite the fact that he has created a situation where misuse is entirely predictable. But if the engineer could, instead of attributing these accidents to 'want of care and recklessness' on the part of the injured workman, apply his ingenuity to devising tamper-proof devices and minimising the need for unofficial access to the danger areas, we could substantially reduce the number of serious machinery accidents.

The last two case studies illustrated the issue of the knowledge and response of engineers with regard to safety and engineering and foreseeable human behaviour. The next two case studies, the accident at Markham Colliery and the Flixborough Explosion, illustrate shortcomings of safety organisation, and to some extent also the shortcomings of engineers in technical competency.

5 Case studies – component and structural failures

The brake failure at Markham Colliery, 1973

On 30 July 1973 eighteen men were killed and eleven seriously injured when the cage in which they were travelling plummeted to the bottom of the number three shaft.

The accident resulted from a failure of the winding engine brake. Fatigue failure of the centre-rod which runs down the middle of the spring nest, resulted from the seizure of the main lever bearing for which no provision at all had been made for lubrication.

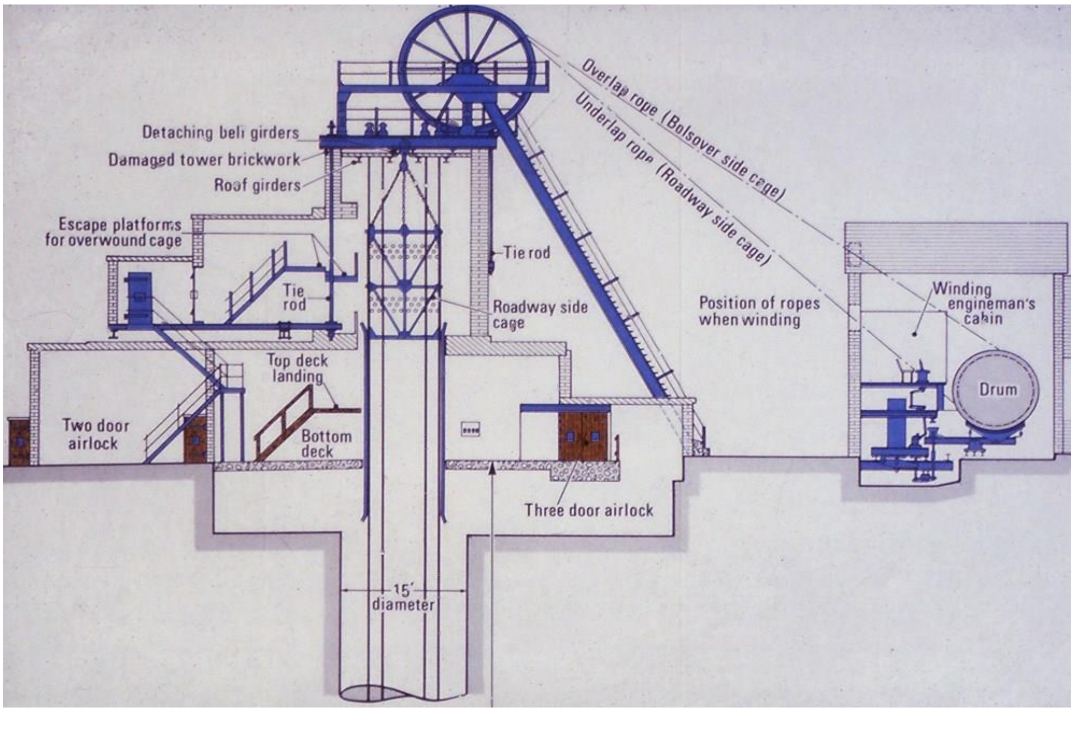

Figure 14: General view of the winding system with the brake drum and brake shoes on the right

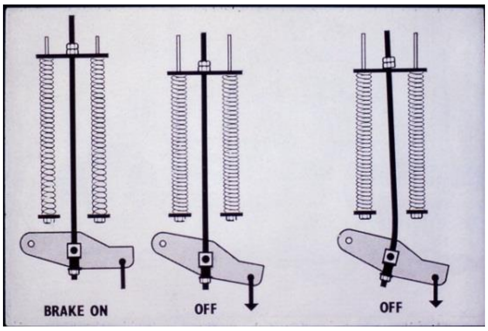

Figure 15: Effects of bearing seizure on the centre rod: cyclical bending stresses. The spring nest provided the force to apply the brakes

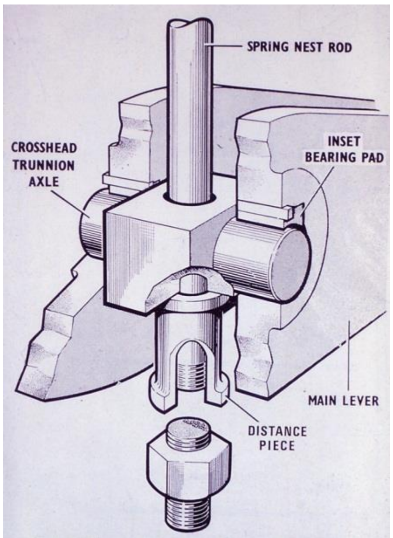

Figure 16: Effects of bearing seizure as a result of no lubrication – fatigue failure of the threaded section of the spring nest rod just above the nut at the bottom

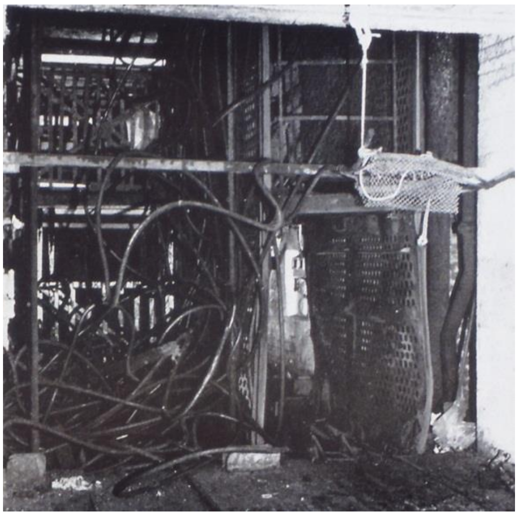

Figure 17: The damaged cage at the bottom of the shaft

The emergency stop button operated by the winding engine man in the last seconds before impact cut out the remaining electrical regenerative braking system. The emergency stop was designed to cope with electrical but not mechanical failures.

The Markham Colliery accident report stated:

"A similar rod… at Ollerton Colliery broke… in 1961. Following this incident the Divisional Chief Engineer issued an instruction that the centre rod in all… spring nests should be examined. This instruction did not give any guidance as to the nature and frequency of the examination required or to the use of non-destructive tests."

"Records showed that an external examination of the… rod was made… but probably because of lack of guidance, it appears that the rod was not removed for… examination at that time, or subjected to non-destructive testing at anytime during its life."

"It appears that the persons at the colliery having responsibility for maintenance had no reason to suspect that the rod was overstressed and, therefore, did not appreciate the need for special methods of testing. Nevertheless the rod was… of adequate strength… and the… crack… could have been found by available means of testing. Also there was a precedent for this type of failure in a similar rod…"

I conclude that while the immediate causes of the accident were in the bearing seizure and fatigue failure, the crucial precondition was a failure in safety organisation – notably the inadequacy of the instructions issued and the apparent absence of a report-back system which included a description of the tests and inspections carried out at each of the collieries which had this particular type of braking system. Regrettably the Court of Inquiry, while mentioning these procedural shortcomings did not pursue the matter in detail.

The Flixborough disaster, 1974

The process plant incorporated six identical reactor vessels numbered 1 to 6, all operating at the same temperature and pressure and containing cyclohexane, a material with similar properties to petrol. On 27 March 1974 cyclohexane was found to be leaking from a stress corrosion crack in reactor number 5. Cyclohexane was in fact leaking from a much smaller crack on the inner stainless steel skin of the vessel. The two square pieces cut out were removed for metallurgical analysis. When the leak was discovered the six engineering managers met to consider the situation. They decided to remove the faulty vessel and replace it with a temporary pipe linking reactor vessels number 4 and 6. The link was badly designed.

Nobody did any design calculations to speak of; nobody consulted the relevant British Standard; nobody consulted the manufacturer's design guide which would have clearly shown that the pipe was unsafe. The design team which consisted of two graduate members of the Institution of Mechanical Engineers was manifestly under great pressure to complete its work so that production could be resumed. No proof test was carried out. At the time production was resumed nobody knew what had caused the failure of the reactor vessel number 5. Moreover no checks had been carried out to determine whether the other five identical vessels were similarly defective.

After two months use, pressure in the system built up to a level fractionally higher than the normal working pressure. The axial bellows squirmed. The mitred joints in the two opening through which cyclohexane emerged in vast quantities. The vapour exploded. The Flixborough Works of Nypro Limited were destroyed.

I would argue that the underlying reason for the Flixborough explosion had little to do, paradoxically, with the basic engineering design errors I have described. The explosion was associated with the complete breakdown of plant safety procedures coupled to a lesser extent with the absence of fully experienced engineers, but of course that is a procedural shortcoming also.

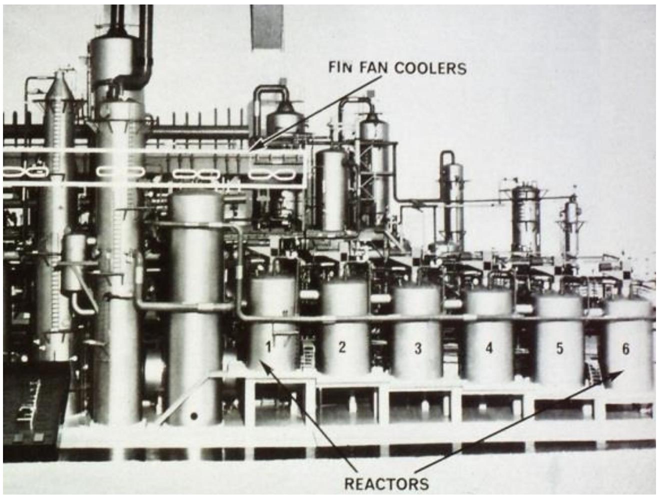

Figure 18: Flixborough – the six cyclohexane reactor vessels

Figure 19: Flixborough - the aftermath

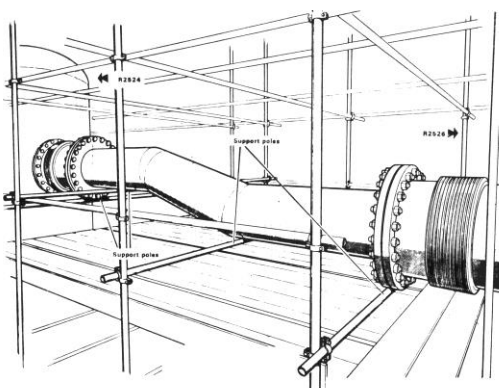

Figure 20: The temporary bridging pipe between vessels 4 and 6

6 The findings of courts of enquiry

The Report of the Flixborough Court of Inquiry (1975) which was concerned almost exclusively with the technical immediate causes of the accident stated:

> *"Although… Nypro was safety conscious, the fact that the explosion at Flixborough did take place shows that by accident, mishap and misadventure, the stage may unconsciously be set for disaster."*
>
> *"We entirely absolve all persons from any suggestion that their desire to resume production caused them knowingly to embark on a hazardous course in disregard of the safety of those operating the works."*

An interesting point is the relatively mild criticisms of serious errors expressed in the Reports of the Courts of Inquiry into the Flixborough Explosion[8] and the Markham Colliery Accident. In contrast 19th and early 20th century Courts of Inquiry usually took an austere view of engineers who had failed to live up to public expectations and competence.

In recent years criticisms of engineers has generally become more muted. One disquieting explanation of this trend which has been suggested to me is that the public perception of the status and competence of the engineering profession has declined in the period to which I have referred. An alternative explanation is that the Inquiries have become so involved in establishing the technical reasons for the accident that the issue of culpability has become blurred. Establishing the immediate cause of an accident beyond all reasonable doubt is often more difficult than preventing the accident in the first place.

I mentioned that early reports on accidents were more austere.

Two examples will suffice to illustrate the point.

Tay Bridge disaster, 1879

The bridge collapsed and with it a train with 75 passengers on board, because of a failure of the bracing ties and the cast iron lugs to which they were secured, in a very severe gale.

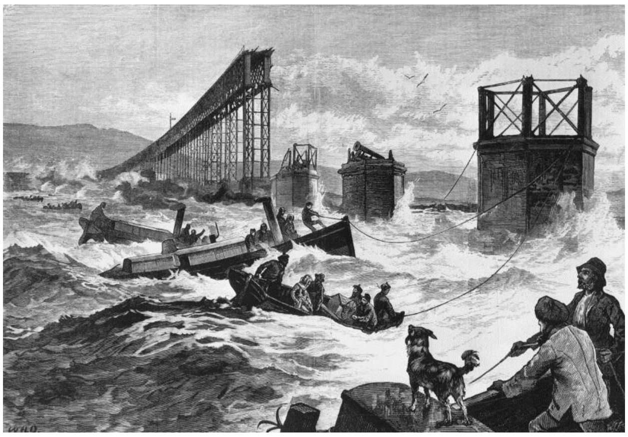

Figure 21: Tay Bridge disaster – the aftermath

8 Dr Joseph Pope (Aston VC) was Vice Chairman of the Flixborough Inquiry. He knew that I was due to be critical of the Inquiry (and engineers). Dr Pope was aware of: Atherley GRC & Booth RT (1975) "Could there be another Flixborough?" Sunday Times 14 September. When I came to work on the following Monday a member of the security staff said to me with glee "that's one in the eye for the VC!"

Sir Thomas Bouch the designer of the Tay Bridge, was severely censured for his shortcomings:

> *"We find that the bridge (the report of the inquiry stated) was badly designed, badly constructed and badly maintained and that its downfall was due to inherent defects in the structure… For these defects in design, construction and maintenance Sir Thomas Bouch is in our opinion mainly to blame." [Minority report]*

Sir Thomas Bouch's reputation was destroyed on publication of the report. He died a broken man shortly afterwards.

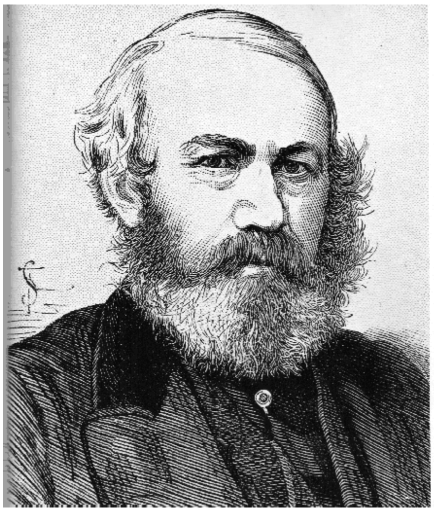

Figure 22: Sir Thomas Bouch

Cammell-Laird Boiler Explosion, 1929 *(photo not available)*

A serious boiler explosion occurred at Cammell Laird's shipyard at Birkenhead. The explosion resulted from corrosion which was not detected by the engineering insurance company: the insurance inspectors did not remove the brickwork to check for corrosion over a period of 15 years. The Inquiry stated:

> *"We hold the Manchester Steam Users Association primarily to blame for the explosion"*
>
> *(The Manchester Steam Users Association were the engineering insurance company)*
>
> *With regard to Mr Petrie, DSc, Chief Engineer to the Association, it is difficult to know what to say. We cannot relieve him of responsibility because he has undertaken to carry out duties which he is wholly incompetent to fulfil".*

He was appointed only a year before the accident happened.

> *"The explosion… cause the death of two men whose lives would have been saved but for the gross neglect of the Association and of the two officers to whom we have referred."*

Although the sharp and sometimes sarcastic criticisms of engineers in Courts of Inquiry some 50 to 100 years ago are, unfortunate, the more recent trend which appears to be to condone the conduct of senior engineers in similar circumstances is also regrettable. The comments of a Court of Inquiry may well be read as a tacit acceptance of poor standards of conduct and competence within a profession.

A weakness of accident inquiries throughout at least until very recently, is that they have tended to study only the immediate causes of accidents, and not the much more important pre-conditions.

7 Concluding comments

The moral that I draw from out studies of engineering accidents is that the underlying reasons for the accidents tend to have only a little to do with conventional engineering skills. Few accidents are attributable to causes which were 'beyond the state of the art', not foreseeable and not reasonably preventable. As I have shown a problem does remain that some engineers, or the persons required to do the engineering work, lack the technical knowledge necessary to cope with the problems with which they are faced. It is not that the technical knowledge has not been discovered, it is that it has not reached or been remembered by the people who need the information and knowledge to prevent the accidents.

But while some accidents are associated with shortcomings of some engineers in their specialist subject, a bigger issues is that engineers lack knowledge, fail to establish and work within closely defined and monitored safety procedures. In some cases the breakdown of safety procedures is not attributable to lack of knowledge it is caused by the conflicting pressures under which engineers work, the laudable objective of getting the job done.

There seem to be two crucial questions:

1. should the education of engineers be broadened to include certain of the topics to which I have referred?
2. given that the answer to the first question is 'yes', does there remain a need for external advice and restraints?

I believe that there is clearly a need to broaden the education of engineers to include some of the subjects to which I have referred. These include:

- (i) management studies
- (ii) an introduction to human behaviour and ergonomics
- (iii) health and safety law, and
- (iv) machinery safeguarding design

It has not been my intention in this lecture to discuss in detail the role of the safety adviser and the enforcement officer. My objective has been to show the problems which can occur in the absence of such advice. Please note that in general I have referred to the giving of advice on safety matters; only in extreme cases is the issue one of veto powers.

The essential point is that technical, behavioural and procedural aspects of safety engineering are at the periphery of most engineers' training and experience. These matters are central to the training and experience of safety advisers and factory inspectors.

While every professional group with a tradition of attainment resists outside interference as an incursion on its sovereignty, I am bound to the view that engineers should listen with an open mind to the opinions of health and safety specialists and take heed of their advice.

In conclusion I believe that safety is too important a matter to be left to the engineers working without advice and without from time to time external restraints on their actions. The achievement of acceptable safety standards demands the combined expertise and pooling of many skills. Only be these means can we reduce the unacceptable toll of pain and suffering experienced at work today as a result of engineering accidents.

BOOTH RT. Safety: too important a matter to be left to the engineers? Inaugural lecture, University of Aston, February 1979.

Republished, mostly in abridged form in:

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