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Accident investigation: Keep asking "why?"☆

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Abstract

Finding the causes of an accident or operating problem and deciding what actions to take to prevent it happening again is rather like dismantling a set of Russian dolls (Fig. 1). Each time we ask "why?" (or a similar searching question) we find another cause besides the ones we have found already and another action (or set of actions) we can take to prevent similar accidents occurring again. Many investigators stop too soon. This occurred at Flixborough, at Bhopal and in the investigation of many lesser-known accidents.

We are more likely to find the deeper causes and the more original actions if groups of people with wide interests and experience are able to take part in the investigations or discuss the investigation reports. We should never look at an accident report as "closing out" a problem. As we read it, we should ask ourselves, "what else could be done?"

Keywords: Accidents, investigation of; Accident reports; Bhopal; Discussions; Flixborough; Inherently safer design; Training

For 14 years, after I retired from industry, I was a member of the safety committee at the largest site of another large company. We received regular summaries of all the accidents and near misses, really near accidents, that occurred but once all the resulting recommendations had been completed the incidents were said to be "closed out" and removed from the lists. However, there is a sense in which accident reports should never be closed out. Different people with different knowledge, experience, interests and outlooks may be able to draw different conclusions from the evidence and suggest different or additional actions. Finding the causes of an accident or operating problem and deciding what actions to take to prevent it happening again is rather like dismantling a set of inter-nested Russian dolls (sometimes called Matrioshkas) (Fig. 1). Each time we ask "why?" (or a similar searching question) we find another cause besides the ones we have found already and another action (or set of actions) we can take to prevent similar accidents occurring again. Many investigators stop too soon. The following pages describe some examples and suggest ways in which people with a broader range of views can consider the evidence.

There is an old saying that "if you ask a question, you open the door; if you answer the question, you close it". I do not suggest that we should not answer questions but too often when we get an answer we think, "that settles it". Instead, we should ask, "what other answers are possible?" or in accident investigations, "what other causes and what other actions are possible?"

Also, when reading a report or listening to a talk, it is easy to comment on what is written or said. It is less easy to spot what is not written or said but might have been. We should look for the words that could fill the white spaces on the paper.

1. Flixborough

The explosion at Flixborough, the worst accident in the UK chemical industry, explosives production excepted, occurred 30 years ago, before many of today's engineers were born, and so it may be worth summarizing the incident. It occurred on a plant for the manufacture of nylon, on a unit that oxidized cyclohexane with air to a mixture of cyclohexanone and cyclohexanol, known as ketone–aldehyde (KA) mixture. The reaction was carried out at a gauge pressure of 9 bar (130 psi) and a temperature of 150 °C (300 °F) in six reactors. The liquid flowed through them in series while the air entered each reactor in parallel. The reactors were mounted on a sort of staircase so that the liquid would flow through them by gravity (Fig. 2).

One of the reactors developed a leak and was removed for repair. It was replaced by a temporary pipe with two bends in it, as shown in Fig. 2. The pipe was badly designed—the only drawing was a chalk sketch on the floor of the workshop—and

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Fig. 1. A set of Russian dolls.

badly supported, it merely rested on scaffolding. There was an expansion joint at each end and this allowed the pipe to rotate or squirm when the pressure rose above the normal level though still below the set point of the relief valve. The pipe ruptured and about 50 t of hot flammable liquids escaped within a minute, instantly vaporized and exploded, killing 28 people, all on site, and destroying the plant. The source of ignition was probably a furnace nearby [1].

The official report [2] drew attention the need for companies to have systems for the control of modifications, temporary or permanent, to plant designs and to make sure that they were built to the same standard as the original plant. The design of the pipe was poor because there was no professionally qualified mechanical engineer on the plant at the time. The works engineer had left and his successor had not yet arrived. Arrangements had been made for a senior engineer from one of the holding companies to be available on request but the men who built the temporary pipe did not see the need to consult him; they did not know that the design of large pipes operating at high temperatures and pressure needed specialized knowledge. They did not know what they did not know.

The official report and most of the commentators on it failed to ask an important series of questions. Once they are asked, the answers are easy.

Why was the explosion so big? Because the leak was so large.

Why? Because the inventory in the plant was large, about 400 t, and the pipes correspondingly large.

Why? Because the conversion per pass was so small, about 6%, so most of the feed got a free ride and had to be recovered and recycled many times.

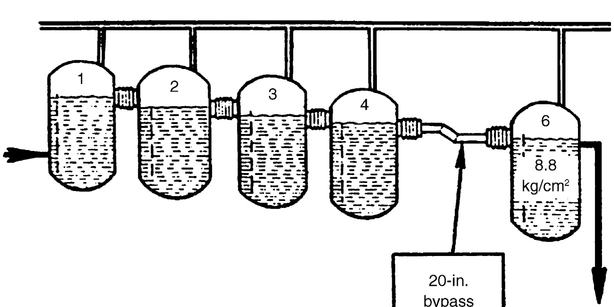

Fig. 2. Arrangement of reactors and temporary pipe at Flixborough.

Why was the conversion so low? Because if the air rate was increased it could not be distributed uniformly and burning would occur?

The staff of one company asked these questions and set out to develop a more efficient process, mixing the cyclohexane with air under conditions in which reaction could not occur and then changing conditions, such as temperature or catalyst concentration. However, the research was abandoned when the company realized that there would be no need for a new plant in the foreseeable future and that there was in fact excess capacity in the industry.

However, the general message was heeded. Flixborough destroyed the confident feeling that we can always keep large quantities of hazardous chemicals under control and therefore we should keep the amounts of them in our plants as low as reasonably practicable or use safer materials instead. Inherently, safer design arrived on the chemical industry's agenda. Many companies and people started to look for ways of reducing inventories in plants and in storage. Of course, there are many earlier isolated examples of this, but Flixborough started the systematic search for them and introduced a new branch of process safety.

Recent research has shown that the conversion of cyclohexane to KA can be doubled by adding water and oxidizing with oxygen instead of air. A Flixborough-type explosion is still possible if there is a large leak but the volume leaking will be lower, there will be less vaporization as the temperature is lower and the water will also vaporize and may reduce the size of the flammable cloud [3].

2. Bhopal

The Bhopal disaster is too well known to need a detailed description but almost all the early publications on it, and many later ones, failed to see the most important lesson it can teach us. A storage tank containing methyl isocyanate, a very toxic liquid, became contaminated with water. This set off a runaway reaction that led to the discharge of tens of tons of methyl isocyanate vapor and the death of thousands of people in an adjoining shanty town. The methyl isocyanate was an intermediate in the production of carbaryl, an insecticide. If we ask why so much was stored, we are told that storage of intermediates is a widespread practice as it allows production to continue in one-half of a plant while the other half is shut down, the intermediate stock increasing or decreasing. Intermediate storage is therefore convenient rather than essential. If instead of storing the intermediate it was used as it was made, the worst possible leak would have been a few kilograms from a broken pipeline instead of tens of tons or more from a leaking tank. Following Bhopal, many companies did reduce their stocks of hazardous intermediates or manage without them, using the intermediates as soon as they were produced.

If we ask if carbaryl must be made from methyl isocyanate, we find that it can be made from the same three raw materials, phosgene, methylamine and alpha-naphthol, by reacting them in a different order so that a less hazardous intermediate is formed [4].

Other questions we might ask are, “could another insecticide, safer to manufacture, be made instead of instead of carbaryl?” and “instead of using insecticides, could we develop pest-resistant plants or use natural predators?” I am not suggesting that such solutions are practicable, only that such questions should be asked. Good loss prevention starts far from the top event on the fault tree.

Whatever the cause of the contamination, the accident would not have occurred or would been less serious if a shanty town had nor been allowed to grow near the plant and if all the protective equipment—vent gas scrubber and flare and tank refrigerator—had been kept in working order. Nevertheless, the chain of events that made the accident possible started when the chemical process was chosen and continued when the decision was made to carry a large stock of intermediate product. Good loss prevention starts far from the top event.

3. Piper Alpha

The destruction of the Piper Alpha offshore oil platform in the North Sea by fire and explosion in 1988 killed 167 people and showed that the hazards of the offshore oil industry were greater than believed by the public and perhaps by the industry itself. The official report [5] was exceptionally thorough and detailed, and showed that the procedures for the preparation of equipment for maintenance and for handling emergencies were poor and poorly enforced. However, the report did not discuss inherently safer design. Afterwards, the Health and Safety Executive sponsored two reports on the extent to which they could be used offshore [6,7] and several publications questioned the need for offshore platforms for the separation of gas and liquids so that they could be separately piped to shore. Would it be possible, they asked, to pump the mixture ashore and separate the oil and gas there. The opinion in the industry was that this was not reasonably practicable but recently Swidzinski has claimed that this is no longer true [8]. The following is his summary of the position:

> Subsea processing or processing in the well itself may simplify and minimise the need for surface facilities, but the need for nearby host facilities to support and receive production from such installations remains. Further process simplification and intensification in the offshore oil and gas industry is unlikely to happen if conventional oil and gas processing philosophy continues to prevail. A possible way forward may be to homogenize the different components associated with oil and gas production and transport these as a controllable slurry to an onshore host facility?

4. A leak from a large distillation column

In contrast to the three major accidents just described, here is an account of a leak of flammable liquid that was thoroughly investigated even though it did not ignite. A crude oil distillation unit was being started up after a major turnaround. Stocks of product were low and it was important to get the unit on line as soon as possible. The unit supervisor (called a manager in

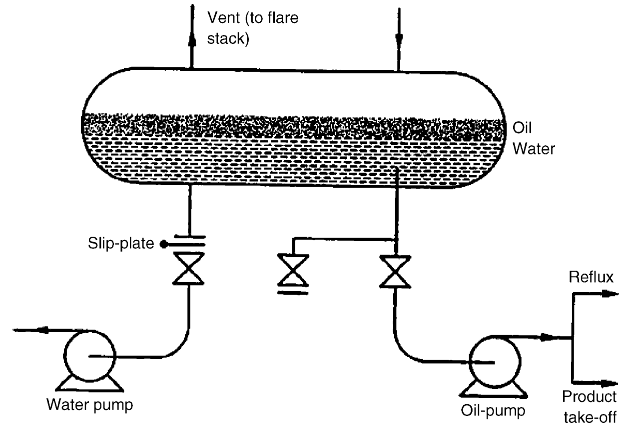

Fig. 3. The reflux drum showing the position of the slip-plate (blind) which should have been removed before start-up. The vessel is actually about 3 m (10 ft) above the slip-plate.

the UK where the incident occurred) was a young graduate who had joined the company only a year before. He decided to be present throughout the night so that he could see what happened during a start-up and also so that he could deal promptly with any problems that arose. Perhaps also his presence might discourage delay.

The distillation column was warming up. The reflux drum was half-filled with water with a layer of light oil containing some liquefied petroleum gas (LPG) on top. Some water was always produced but as the column had been washed out the production of water was greater than usual. Two pumps were connected to the reflux drum as shown in Fig. 3. The water pump took suction from the bottom of the drum and sent the water to a scrubber for purification and discharge to drain; the oil pump took suction from a point about 30 cms (1 ft) above the bottom and provided reflux and product take-off. Neither pump had been started up.

The foreman asked an operator to start-up the water pump. The operator discovered that a blind (slip-plate) had been left in the suction line to the pump on the drum side of the isolation valve (Fig. 3). All the branches on the drum had been blinded during the turnaround to isolate the drum for entry for inspection. The other blinds had been removed but this one had been overlooked by the mechanic who removed them and this was not noticed by the process foreman when he accepted back the permit-to-work.

The supervisor estimated that shutting down the furnace, allowing it to cool, fitting a hose to the spare branch on the reflux drum, draining the contents to a safe place, removing the blind and warming up again would result in 24 h delay. The maintenance foreman, a man of great experience, who was also present throughout the night, offered to break the joint, remove the blind and remake the joint while the water ran out of it. He could do it, he said, before all the water ran out and was followed by the oil; he had done such jobs before.

After some hesitation, the supervisor agreed to let the maintenance foreman go ahead. He dressed up in waterproof clothing and watched by the process team, unbolted the joint and removed the blind while the water sprayed out. Unfortunately, he tore one of the gaskets, half of it sticking to one of the joint faces. Before he could remove it and replace it, all the water ran out and was followed by the oil. Some of the LPG flashed as the oil came out of the broken joint. The foreman realized that his waterproof clothing would provide no protection if the leaking liquid ignited so he abandoned the attempt to remake the joint.

The furnace was only 30 m (100 ft) away. As soon as the oil appeared, one of the process team pressed the button that should have shut down the burners. Nothing happened. The process team had to isolate the burners one by one while the oil and vapor were spreading across the level ground towards the furnace. Fortunately, they did so without the vapor igniting.

Afterwards, it was discovered that the trip system on the furnace had given trouble a day or two before the turnaround started. The process foreman on duty therefore took a considered decision to disarm it until the turnaround, when it could be repaired. Unfortunately, there was so much work to be done during the turnaround that this late addition to the job list was overlooked.

Although there was no injury or damage, both could easily have occurred. The first two sets of recommendations described below were made by the investigating panel. The other three were made later when the incident was selected for discussion by groups of 12–20 people, from senior managers to senior foremen and including design engineers, as part of a training programme. As we shall see, the various recommendations are not alternatives. All are necessary if a repeat of the accident is to be prevented and all apply widely, not just to the unit, factory or company where the accident occurred.

Part 1—*Why was one blind overlooked when the others were removed and how can we prevent this*? The inquiry recommended that:

- All blinds should be listed on a permit-to-work. It is not sufficient to say, as the permit said, “remove all blinds (or slip-plates) from all branches on reflux drum”. Instead their positions should be listed and identified by numbered tags. “All” is a word that should be avoided when writing instructions on safety matters. Other imprecise words that should never be used in instructions are “similar”, “more” and “less”, unless we are told how much more or less.
- When a maintenance job is complete, the process foreman, before accepting back the permit-to-work, should check that the job done is the job he wanted done and that all parts of it have been completed.
- All blinds inserted during a turnaround should be entered on a master list and a final inspection made, using this list, before start-up. At a recent discussion, someone suggested giving each blind a bar code number and then using a bar code reader to confirm that all the blinds had been removed.
- If the blind had been inserted below the isolation valve, it would have been possible to remove it with the plant on line. Nevertheless, we should continue to insert blinds on the vessel side of isolation valves as if they are fitted on the far side liquid might be trapped between the blind and a closed valve and then slowly evaporate while people were working in the vessel. Such incidents have occurred.

Part 2—*Why did the furnace fail to shut down and how can we prevent this*? The inquiry recommended that:

- Protective equipment should not be by-passed or isolated unless this has been authorised in writing by a responsible person.
- If it is by-passed or isolated, this should be signalled to the operators in some way, for example by a light on the panel. A note in the shift log is not enough.
- All interlocks (trips) that have been repaired or overhauled should be tested before they are put back into service.
- The ground should have been sloped so that any liquid spillage flowed away from the furnace. In general, spillages should flow away from equipment, not towards it.

This is as far as the formal investigation went, but when groups discussed the incident, spending about an hour on it, they asked extra questions and produced the following answers, though no group produced them all.

Part 3—*Why was the hazard not foreseen*? Removing the blind was more hazardous than seemed at first sight because the gauge pressure at the blind, due to the head of liquid, was nearly 0.7 bar (10 psi) higher than the pressure in the reflux drum (a gauge pressure of about 1 bar (15 psi). This might have been realized if those present had given themselves time to talk over the proposed course of action. Simple calculations could have avoided many other accidents [9].

What else could have been done?: A shut down could have been avoided with less risk by freezing the water above the blind with solid carbon dioxide (dry ice) or by injecting water into the reflux drum via the spare branch shown in Fig. 3 so as to maintain the water level. Another possible way of avoiding the shut down would be to remove the pump, pass a drill through the valve and drill through the blind. This method could, of course, only be used if the valve was a straight-through-type.

As a general rule, when we have to decide between two courses of action, both of which have disadvantages, we should look for alternative actions. They are often possible.

How much time elapsed between discovering the presence of the blind and deciding to let the foremen remove it?: The discussion groups saw a rushed decision by the supervisor as a key event. Few problems on a large plant are so urgent that we cannot delay action for 15 min while we talk them over. If those concerned had paused for a cup of tea, they would have realized that removing the blind was more hazardous than it seemed at first sight and that as described above, there were other ways of avoiding a shut down.

Part 4—*Who was in charge*? This was not clear. Was the young supervisor there to see how his team handled a start-up, leaving the decisions to the experienced process foreman who would normally have been on his own, or was the young supervisor in command? The discussion groups saw the accident as due to the failure of the young supervisor to stand up to the maintenance foremen. The supervisor’s situation was difficult. The maintenance foreman was a strong personality, widely respected as an experienced craftsman, old enough to be the supervisor’s father, and he assured the supervisor that he had done similar jobs before. It was 3 a.m., not the best time of day for decisions. The supervisor could not be blamed. Nevertheless, sooner or later, every supervisor has to learn to stand up to his staff, not disregarding their advice, but weighing it in the balance. He should be very reluctant to overrule them if they are advocating caution, more willing to do so if, as in this case, they want to take a chance.

The maintenance foreman felt partly responsible for the non-removal of the blind. This made him more willing than he might otherwise have been to compensate for this error by taking a chance. A more experienced supervisor would have realized this.

What training did the company give to young graduates to help them cope with situations like this one? The company's policy was to teach them to swim by pushing them in the deep end. This is excellent training for the graduates, as I know from personal experience, but it is not always good for the plant.

Part 5—Some discussion groups went deeper than the others and asked questions such as, *was the incident due to a failure to give sufficient emphasis to safety throughout the organization*? *What would the factory manager have said the next morning if he found that the start-up had been delayed*? *Would he have commented first on the low stocks and lost production or would he have said that despite the low stocks he was pleased that no chances had been taken*?

The discussion groups concluded that the young unit supervisor was not working in a vacuum. His judgement was influenced by his assessment of his bosses' reactions and by the attitude to safety in the company, as demonstrated by the actions taken or remarks made in other situations. Official statements of policy have little influence. We judge people by what they do, not what they say. The factory manager carried a large share of responsibility for setting a climate, probably inadvertently, in which his staff felt that risk-taking was legitimate.

Did the unit supervisor feel that he had been given, by implication, contradictory instructions, in this case to get the plant back on line as soon as possible and at the same time, to follow normal safety procedures? Supervisors and foremen often find themselves in this position. Senior managers stress the importance of output or efficiency but do not mention safety. So, their subordinates assume that safety takes second place. They are in a "heads you win, tails I loose" situation. If there is an accident, they are blamed for not following the safety procedures. If the required output or efficiency are not achieved, they are blamed for that. Managers, when talking about output and efficiency should bring safety into the conversation. What we do not say is as important as what we do say.

It may be right, on occasions to relax the safety rules, but if so this should be clearly stated, not hinted at.

How, if at all, did the young graduate's training in the company and at University prepare him for the situation in which he found himself? Probably, not at all. Today, in the UK, all undergraduate chemical engineers receive some training in loss prevention though it is unlikely to cover situations such as that described.

The following other comments were made during the discussions. The accident, like most accidents, was not the fault of a single person. Many people shared responsibility, those who failed to remove the blind, those who by-passed the furnace trip and then failed to make sure that it was repaired, the young supervisor, those responsible for his training and guidance, the maintenance foreman, the factory manager. Any of these people, by doing their job better, could have prevented the incident. At the operating level, those concerned were following custom and practice, and the greater responsibility is therefore that of the factory manager and his senior colleagues who either failed to recognise the deficiencies in their procedures or failed to do anything about them.

5. Three incidents in an oil company

An official report [10] described three incidents that occurred in a large oil company in the same year. As you read the following summary of them, see if you can spot something that has not been said and applies to all of them.

5.1. Incident 1

Liquid accumulated in a dip in a blowdown line (see Fig. 4), leaked out and caught fire. Two men were killed.

Why did liquid accumulate? Because isolation for maintenance depended on a large valve that leaked and not on blinds (slip-plates) and because the drain line on the tailpipe was choked. Also, the isolations necessary for maintenance were left to two foremen to sort out shortly beforehand. They were not planned well in advance of the report (§15–16).

Why did a leak occur? Because the joints were not broken in the correct manner; all the bolts were removed and a slip ring pulled out. Some bolts should have been left in and the joint opened gradually with a flange spreader (§36).

Why did the leak ignite? It was ignited by a diesel engine. Many people do not realize that diesel engines can ignite leaks.

Why could the men not escape? Because the access for maintenance was poor, the mechanics had to crawl under or over the

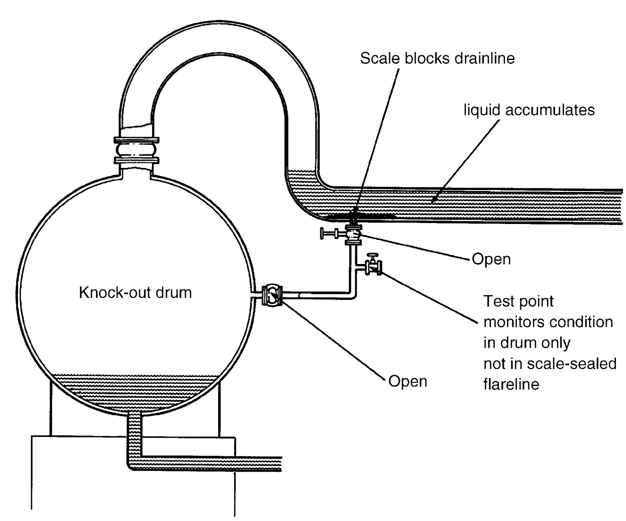

Fig. 4. Liquid accumulated in the dip in the blowdown line as the drain line was blocked.

body of a large valve (§19) and when the leak ignited, they were "engulfed in the fire" (§26).

5.2. Incident 2

Liquid was let down from a high pressure vessel to a low pressure one. When the liquid level was lost, high pressure gas passed into the low pressure vessel; its relief valve was not big enough to protect the vessel and it burst. A piece weighing 3 t was found 1 km (0.6 mile) away. One man was killed. The vessel burst despite the presence of a trip system to prevent overpressuring of the low pressure vessel.

5.3. Incident 3

Was a fire in a crude oil tank while sludge was being cleaned out. Vapor given off by the sludge was ignited by illegal smoking by contract cleaners who had removed their breathing apparatus so that they could smoke and see better. Although the measured gas concentration was only 25% of the lower explosive limit, the concentration was not uniform as sludge was being disturbed. The tank was not force-ventilated and no thought had been given to means of escape. One man, a non-smoker, was killed, perhaps because his airline became entangled with support pillars and hindered his escape.

5.4. The common factor

As many readers may have realized the official report failed to mention that all the errors described above have occurred before and have been described in published reports, some of them many times. In the following, I have quoted references that predate the incidents rather than recent ones.

Ref. [11] describes a major fire, the result of liquid collecting in a dip in a blowdown line. On the refinery, there was a small-bore line to drain off any liquid that accumulated but it was blocked by scale. A warning that small-bore lines can block in this way is included in the refinery's piping systems code (§32 of the report).

It has long been recognized and frequently stated that thorough isolation requires blinds, disconnection or double block and bleed valves. In ICI's Billingham, UK factory, this was stated in the *Safety Handbook* given to all employees in 1929. It was quoted in a 1977 paper [12].

A similar incident, though involving toxic gas, is illustrated in one of the Hazard Workshop Modules, collections of slides and notes illustrating accidents that have occurred published by the UK Institution of Chemical Engineers [13]. Work on blowdown lines is particularly liable to result in spillages and in another incident a fitter escaped by sliding down a pipe like a fireman down a pole [14].

The fact that diesel engines can ignite leaks was widely publicized following a 1969 fire [15]. In the refinery incident, the exhaust gas spark arrestor was missing (§35). Ref. [16] describes another ignition by a diesel engine.

The cause of the second incident was a classical one. Ref. [17] examines a similar situation in detail but as there were two let-down valves in parallel, a glance at the drawings, without detailed calculations, should have shown anyone familiar with reliability calculations that the hazard rate was too high. In addition, the trip system was not in working order.

The fact that sludge at the bottom of a tank can release gas when disturbed has been known for a long time [18]. Also this incident, like many others going back many years, shows again the need for close supervision of contractors [19].

The official report thus missed a major recommendation that it ought to have made: *we need to do more to prevent us forgetting the lessons of the past*. I have described elsewhere many other accidents that have occurred for the same reason and some of the things we could do to help us remember the lessons of the past [20]. All the incidents described in this paper occurred some years ago but all teach us lessons we should not forget.

6. When do we stop asking "why?"

I have stressed the importance of asking this question or a similar ones (the way we phrase a question can effect the answer) but when do we stop asking, when do we decide that we have got to the core of the Russian doll? A common answer is to say, "we should stop when we have got to the limit of what we, the members of the investigating panel, have the ability and authority to change. We have got the plant and we can only go so far in modifying it". This true but the panel should still note changes that could be made to future plants, and discuss them with the design organization.

Similarly panels may say, "we cannot change the law or the national codes and standards". But they can suggest changes.

Investigators may be in a difficult position when they feel that an underlying cause of an accident is the organization's policy or culture. Their bosses may resent implied or explicit criticism. This did not prevent some of the discussion groups who discussed the leak from the large distillation column (see Part 5 above) from questioning the culture of the factory but other organizations may be less open.

Accident investigators are usually close to the job so their main objective is to correct the immediate technical faults that caused the incident and get the plant back on line. Putting the world right is not their problem. We can overcome both these constraints if people from other units or other sites are included in investigation panels and if incidents are discussed by a group of people from other units and other functions, with other interests, backgrounds and experience, as described above. These discussions were started as training exercises and this was their main purpose but they threw fresh light on incidents that had, everyone thought, been "closed out".

Accident reports are rather like Rorschach inkblots. Different people see different underlying causes.

7. A final thought

Learning from experience is a lantern on the stern, illuminating the hazards the ship has passed through. It is essential to do so as we may come the same way again. However, we should also have a lantern on the bow so that we can see the hazards that lie ahead. Hazop is a lantern on the bow.

References

[1] T.A. Kletz, Learning from Accidents, third ed., Butterworth-Heinemann, London, 2001 (Chapter 8).
[2] R.J. Parker (Chairman), The Flixborough disaster, Report of the Court of Inquiry, Her Majesty's Stationery Office, London, 1975.
[3] J.-R. Chen, An inherently safer process of cyclohexane oxidation using pure oxygen—an example of how better process safety leads to better productivity, Process Saf. Prog. 23 (1) (2004) 72–81.
[4] T.A. Kletz, Learning from Accidents, third ed., Butterworth-Heinemann, London, 2001 (Chapter 10).
[5] W.D. Cullen, The Public Inquiry into the Pipe Alpha Disaster, Her Majesty's Stationery Office, London, 1990.
[6] AEA Technology, Improving Inherent Safety—A Pilot Study, HSE Books, Sudbury, UK, 1997.
[7] D. Mansfield, L. Poulter, T.A. Kletz, Improving Inherent Safety, HSE Books, Sudbury, UK, 1997 (HSE Offshore Technology Paper No. OTH 96 321).
[8] M. Swidzinski, Process ontensification: an offshore oil and gas industry perspective, Minutes of the 10th Meeting of the Process Intensification Network, 3 June, www.pinetwork.org, 2004.
[9] T.A. Kletz, Still Going Wrong—Case Histories of Process Plant Disasters and How They Could Have Been Avoided, Gulf Professional, Boston, MA, Sections 3–1, 8–7 and 13–7, 2003.
[10] Anon., The Fires and Explosion at BP Oil (Grangemouth) Refinery Ltd., Her Majesty's Stationery Office, London, 1989.
[11] T.J. Laney, Lessons from the Aramco tank fire, in: C.H. Vervalin (Ed.), Fire Protection Manual for Hydrocarbon Processing Plants, vol. 1, third ed., Gulf Publishing, Houston, TX, 1963, pp. 101–105 (presented at the American Gas Association Production-Chemical Conference, and reprinted with some revisions).
[12] T.A. Kletz, What are the causes of change and innovation in safety, in: Second International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Heidelburg, Dechema, Frankfurt, Germany, September 1977, 1993, pp. 1–13 (reprinted in lessons from disaster, Institution of Chemical Engineers, Rugby, UK, 5).
[13] Anon., undated (about 1978), Hazard Workshop Module, Preparation for Maintenance, Institution of Chemical Engineers, Rugby UK) (the later editions are called Training Packages).
[14] T.A. Kletz, What Went Wrong? Case Histories of Process Plant Disasters, first ed., Gulf Publishing, Houston, TX, 1985 (fourth ed., 1988, Section 10.4.3).
[15] Anon., Chemical Age, 12 December, p. 40 and 9 January 1970, p. 11, 1969 (similar reports appeared in many other journals).
[16] T.A. Kletz, Learning from Accidents in Industry, Butterworths, London, 1988 (Chapter 5) (the third ed., 2001 called 'Learning from Accidents', is published by Gulf Professional, Oxford, UK).
[17] T.A. Kletz, H.G. Lawley, Safety technology in industry: chemical, in: A.E. Green (Ed.), High Risk Safety Technology, Wiley, Chichester, UK, 1982, pp. 317–352.
[18] T.A. Kletz, Hazards in chemicals system maintenance: permits, in: H.H. Fawcett, W.S. Wood (Eds.), Safety and Accident Prevention in Chemical Operations, Wiley, Chichester, UK, 1982, pp. 807–836.
[19] T.A. Kletz, Learning from Accidents, third ed., Gulf Professional, Oxford, UK, 2001 (Chapters 5 and 17 and Sections 14.4, 16.5 and 25.3).
[20] T.A. Kletz, Lessons from Disaster—How Organisations Have No Memory and Accidents Recur, Institution of Chemical Engineers, Rugby, UK, 1993.