It’s not what we don’t know that is the problem; it’s what we do know that isn’t so

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‘Uncertainty’ is a term that has been incorporated into the definition of risk in some standards and regulations. The definition of risk in ISO 31000, for example, is the ‘*effect of uncertainty on objectives*’. The Petroleum Safety Authority in Norway has recently changed the risk definition in their HSE regulations to ‘*Risk means the consequences of the activities, with associated uncertainty’.* The term ‘uncertainty’ is intended to address both stochastic uncertainty, sometimes called irreducible risk, e.g. the probability of a number at roulette, and epistemic uncertainty, i.e. lack of knowledge. Uncertainty in the sense of ‘unpredictable’ or ‘unknowable’ has also been connected with risk and is associated with ‘black swan’ events made famous by Nassim Nicholas Taleb in his book ‘The Black Swan’. This type of uncertainty is not considered in this paper.

The focus on ‘uncertainty’ seems logical in certain situations, for example when considering ‘knowledge strength’ in structured decision making processes. Uncertainty on what constitutes sufficient knowledge on issues that are relevant to decisions drives the analyses and evaluations needed to attain the required knowledge. A focus on ‘uncertainty’ arguably makes the organisation, and in particular, the decision maker, more conscious of what is required to take a decision.

The investigation into major accidents often reveals actions taken, and/or assumptions made, by organisations and/or people that turn out to be wrong. The knowledge that was the basis for the actions and assumptions was either incorrect, not appropriate in the particular circumstances or misunderstood. This implies that ‘certainty’ or ‘perception of certainty’ is arguably a more important factor in major accidents than uncertainty. How does this assertion hang together with the assessment of major accident risk bearing in mind that risk is defined in terms of ‘uncertainty’? Is ‘uncertainty’ the right focus, or should there be more focus on ‘perception of certainty’ and ‘what we know that isn’t so’.

This paper will use the terms ‘belief’ and ‘believe’ in the context of knowledge that guides actions and assumptions rather than the context of knowledge that indicates truth. A model for how knowledge, certainty belief and action interact is described and the terminology ‘incorrect belief’ is used for ‘what we do know that isn’t so’. This paper is intended to highlight the importance of ‘incorrect belief’ in major accidents, explain some of the key processes that lead to ‘incorrect belief’ and how organisations allow ‘incorrect belief’ to take root and develop. Methodologies will be suggested to identify and change ‘incorrect belief’.

Paper Title

The title of this paper is based on a quote from Trevor Kletz. The original quote is attributed to Mark Twain ‘*What gets us into trouble is not what we don’t know; it’s what we do know that just ain’t so’*. Like many quotes attributed to Mark Twain there is some controversy into whether he made the quote as it doesn’t seem to be appear in any of his published material. However, like most quotes from Trevor Kletz and Mark Twain, the sentiments seem to be appropriate and hopefully some reflection on these sentiments will lead to a better understanding of why people do what they do even though what they do leads to a major accident.

The risk definition and the application of uncertainty

One point that is perhaps pedantic, but is worth mentioning, is whether a definition of risk based on uncertainty of consequences is actually appropriate when considering major accidents. Since the definition of a major accident implies significant consequences, then the uncertainty related to these consequences is arguably irrelevant and at least of limited use. When considering major accidents, the only meaningful focus is prevention. The prevention of the initiating event and the prevention of the escalation of this event that results in significant consequences for people, the environment and material and property. This is in line with current thinking on barriers and the defence in depth concept described by Dr. James Reason. The reason this is worth mentioning is that the prevention of major accidents should not be made more complicated than it needs to be. Introducing new terms and definitions can easily distract organisations. Valuable resources can be spent on interpretation of the new requirements and development of methodologies to satisfy the new requirements. It may be possible to document compliance with the new requirements; however will this work actually lead to improved prevention of major accidents? This is not to suggest that there should be no new terms and definitions or ways of approaching risk. Rather that any new approach to risk should show a logical progression to major accident prevention and not lead to abstract discussions that have little real value.

Another reflection that is important in the context of major accidents is the benefit of uncertainty in prevention. Uncertainty can lead to caution, stopping up, rethinking, getting more knowledge, carrying out more analyses, verifying assumptions, and in particular challenging the knowledge we have. Andrew Hopkins, a Professor in Sociology, has studied many major accidents and encourages us to be forever sceptical, and be constantly on the lookout for warning signs. Uncertainty can be a useful tool in this quest.

What do we mean by certainty and knowledge?

According to one definition, ‘certainty’ is *perfect knowledge that has total security from error, or the mental state of being without doubt*. In many situations, it is not probable, or even possible, that a person or an organization has perfect knowledge of both a situation and the circumstances around a situation. Furthermore, there is no guarantee that the possession of perfect knowledge will lead to the application of this knowledge in the right way. *The mental state of being without doubt* is a more useful way to define certainty in the context of this paper. ‘Being without doubt’ or ‘not having enough doubt’ leads to a perceived certainty and the perceived certainty is the basis for the actions that people and organisations take.

According to one definition knowledge is *a familiarity, awareness or understanding of someone and/or something, such as facts, information, descriptions or skill. Knowledge can be acquired through education, experience, perceiving, discovering or learning.* This seems a useful definition for the purposes of this paper. Two other aspects of knowledge are important. The first is the distinction between individual knowledge and organisational knowledge and in particular the distinction on how individual and organisational knowledge is attained and influenced. The second is the distinction between knowledge that is conscious and unconscious, sometimes referred to as ‘what we know we know’ and ‘what we don’t know we know’. This distinction is important since both types of knowledge influence actions that individuals and organisations take.

In order to rationalize the connection between certainty and knowledge and to apply these to people, as individuals and in organisations, the terms ‘belief’ and ‘believe’ will be used. ‘Belief’ in this context is associated with guiding action rather than indicating truth (ref. Wikipedia and reference to Jonathan Leicester).

Belief in the context of this paper can also be related to ‘mental models’ or ‘paradigms’. Peter Senge in his book ‘The Fifth Discipline’ describes mental models as ‘*deeply ingrained assumptions, generalizations, or even pictures of images that influence how we understand the world and how we take action*’. The key point here is the connection between beliefs or mental models and their influence on actions.

How do we acquire knowledge and what influences this knowledge?

Individuals start to acquire knowledge from birth, some maintain even before birth, and continue to acquire and accumulate knowledge throughput their life. This is the process of learning. Learning can come from experience and education and learning leads to both conscious and unconscious knowledge, what we know we know and what we don’t know we know. The beliefs that guide an individual’s action are influenced by both conscious and unconscious knowledge. This is an important point in the understanding of the assertion that ‘it’s not what we don’t know that is the problem; it’s what we do know that isn’t so’. The ‘what we do know’ contains both conscious and unconscious knowledge and there may be different processes required to identify and change knowledge that is not correct.

Knowledge in organizations is related to the collective knowledge of the individuals and the accumulation of experience of the organization in carrying out its activities. Organisational learning is a subject in itself and the study of organizational learning can be traced back to the late 1970s for example with work of Chris Argyris and Donal Schon. Organizational knowledge also has a ‘conscious’ and ‘unconscious’ element that needs to be recognized. Explicit knowledge, for example standards processes and procedures can be considered as ‘conscious’ knowledge. ’Unconscious’ knowledge is more related to the way the organization actually works and hence is closely related to the culture in the company. For example, the unwritten rules that have been developed that express ‘how we do things here’. Both the ‘conscious’ and ‘unconscious’ organisational knowledge are key factors to ‘what we do know that isn’t so’ and again these may require different processes to identify and change knowledge that is not correct.

A model to demonstrate the relationship between knowledge, certainty, belief and action is shown in figure 1. Individuals or organisations have knowledge related to the situation and the circumstances surrounding the situation. The individuals or organisation carry out an evaluation of this knowledge related to certainty and this evaluation can be either conscious or unconscious. The individual or organisation then has established a belief that leads to an action.

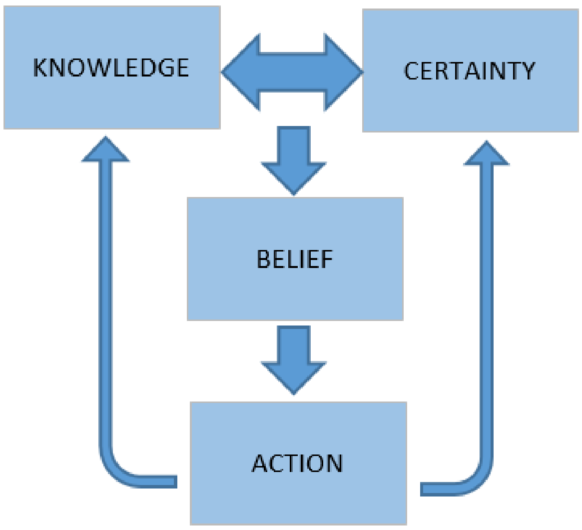

Figure 1. Relationship between knowledge, certainty, belief and action

What are the processes that lead to 'incorrect beliefs'?

In order to avoid any controversy on the use of the term 'belief' then the definition used in this paper will be restated. 'Belief' is associated with guiding action rather than indicating truth.

Processes that lead to incorrect beliefs may be inadequate competence and training, poor awareness, arrogance, inability to resolve complex situations with multiple factors or physical and psychological processes. They could be related to memory lapse, misunderstanding or confusion. They could be related to sociological processes like groupthink, cognitive bias, peer pressure, obedience to authority, etc. It is not the intention of this paper to identify and explain all the processes that could lead to incorrect beliefs, in itself a mighty task.

Using the model described in figure 1, six major accidents were studied to illustrate two of the key processes that create incorrect beliefs, confirmation bias and normalization of deviance. An awareness of how confirmation bias and normalization of deviance can lead to 'what we do know that is not so', and implementation of some practical methodologies to combat these phenomena, can contribute to the prevention of major accidents. These methodologies may also address other processes that lead to incorrect beliefs. The key point in using the methodologies is to specify what is being looked for at the outset.

How 'certainty' has contributed to major accidents.

The Kegworth air crash in January 1989.

A Boeing 737/400 took off from Heathrow on route to Belfast. A fatigue crack in a turbine blade in the left motor caused significant vibration in the plane and there was a smell of smoke in the cockpit. A damaged piece of the turbine blade most likely embedded itself in the housing of the engine. The vibration made it difficult for the first officer to see which engine had the problem. The difficulty on reading the vibration gauges on the 737 when the plane was vibrating, had been reported in earlier incidents without any action being taken including informing the crews of the potential problem. The first officer informed the captain, first that the problem was related to the left engine then that it was related to the right engine. The captain decided to shut down the right engine. The captain's knowledge of the 737 was extensive and he believed that the cockpit air conditioning came from the right engine only; hence, the smoke must be coming from the right engine. At the same time as the right engine was shut down power was reduced on the left engine. This stabilized the airflow through the left engine and reduced the vibration. The actions taken by the captain appeared to solve the problem. When the pilot attempted a landing at British Midland airport the power was increased to the left engine and the damaged piece was most likely dislodged and drawn into the engine causing a catastrophic failure. The plane crashed only 600 meters from the runway. Attempts by the crew to start the right engine when the left engine failed were too late. Of the 118 people aboard, 47 died and 79 sustained serious injuries.

The Boeing 737/400 was a new plane, and a new version. The previous version of the 737 that the captain was familiar with did have the air conditioning for the cockpit taken from the right engine. On the new version the air conditioning for both the cockpit and cabin were taken from both engines. The captain was not aware of this change. The smoke confirmed his belief that the right engine should be shut down. The reduction in vibration confirmed that the actions taken solved the problem. These confirmations led to the captain not seeking any further information on the engine failure.

Texas City refinery explosion and fire, March 2005.

During start-up of the isomerization unit at BP's Texas City oil refinery the CCR operator monitored the level transmitter in the raffinate splitter tower and the level rose above the high-level alarm generated from the transmitter as the feed was introduced. As the filling continued, the reading from the level transmitter indicated about 10 ft. and falling. A separate high-level switch was not activated during the filling process. It was normal practice to overfill the splitter on start-up although the procedures stated otherwise. The CCR operator had a mental model of the how the start-up of the isomerization unit should be, the indicators confirmed this model, and hence his belief that this was a normal start up. The discharge valve from the tower had been closed by the previous shift and this had not been noted in the CCR logbook. The splitter was eventually overfilled and the PSVs lifted and discharged to a blowdown drum. The blowdown drum had an open vent and a liquid drain and was not designed for the developing scenario. Hot raffinate emerged from the blowdown drum, formed a gas cloud that was ignited by a diesel pick-up truck, with its engine running, located near the blowdown drum. 15 people were killed and 180 injured.

The level measurement on the raffinate splitter was not designed to indicate a reliable level once the maximum level had been exceeded. The separate high-level alarm switch failed to function most likely due to inadequate maintenance. The CCR operator had just completed 29 consecutive 12-hour shifts and had other unit operations to monitor in addition to the start-up of the isomerization unit. The practice of overfilling the splitter on start-up had been normalized and the CCR operator was most likely looking for signs of confirmation that the start-up was progressing as expected rather than looking for anomalies that would indicate problems.

Deepwater Horizon in April 2010

The crew on the drilling rig Deepwater Horizon were completing their work on the Macondo subsea well in the Gulf of Mexico. The well had been extremely challenging and there was 'pressure' to complete the well and get the rig off station. The drill crew had just cemented the well casing and believed that this was successful based on drilling mud returns during the cementing operation. Since the operation was considered a success, they saw no need to carry out a cement bond log to check the quality of the cement placed between the casing and the formation. The drill crew carried out an inflow test (negative pressure test) to confirm the well was isolated from the reservoir and that the integrity of the cement for satisfactory. They believed that the results of the inflow test confirmed that the cementing operation was successful. During the subsequent circulation of the well to seawater, the drill crew did not monitor the well or the drilling mud returns to detect any signs of well flow. They did not have the diverter system lined up to the flare system and personnel were not prepared to activate the Blowout Preventer (BOP) at short notice. The well was not properly isolated from the reservoir and it started to flow. The Blowout Preventer did not cut the pipe and seal the well due to orientation of the drill pipe in the BOP. The gas emerging from the well ignited and 11 people died in the explosion and fire. 5 million barrels of oil flowed into the Gulf of Mexico and the incident cost BP over USD 60 billion.

The read out from the pressure test indicated the well was not stable. The pressure build up was out with the normal acceptance criteria for such a test. The drill crew managed to explain the anomaly with the pressure test by introducing a concept called 'the bladder effect' an erroneous theory unrelated to the situation with a negative pressure test. The drill crew eventually managed to get an acceptable pressure build up using a separate line from the well (the kill line) that was most likely blocked with drilling solids. No attempt was made to explain the anomalies between the different pressure readings.

The certainty that the cementing operation had been successful led the drill crew to believe that the well was isolated and stable. This certainty led the drill crew to look for knowledge that confirmed their belief and exclude knowledge that contradicted their belief.

Andrew Hopkins in his book 'Disastrous Decisions' described the process of confirmation bias when the drill crew discussed and agreed on the interpretation of the results of the pressure test on the Macondo well. The reference to 'the bladder effect' seemed to strengthen the confirmation bias that was already at work. The drill crew and the well team onshore just wanted to get this well secured and move the rig off station. The Macondo well had caused a number of serious problems and had clearly started to affect the morale and the judgement of the people involved in the work both onshore and offshore. They wanted the cement to be good and they believed it was. They looked for signs that confirmed their view that the test was satisfactory, they looked for explanations to describe anomalies on the pressure response, and they looked to establish a consensus in the decision-making.

Iran Air Flight 655 shot down by USS Vincennes in July 1988

During the Iran-Iraq war, US Navy ships were engaged in the Persian Gulf to protect shipping in international waters. The captain of the USS Vincennes was ordered to send his helicopter to assist another US Navy vessel in the area with an engagement with Iranian gunboats. As well as sending the helicopter, the captain turned the vessel towards the conflict area without confirmation from the commanding officer in the area or the captain of the vessel he was supporting. The ships helicopter was fired upon and the rules of engagement allowed the captain of the Vincennes to engage the gunboats. In this engagement, the USS Vincennes sailed into Iranian waters.

Flight 655 was a scheduled flight from Tehran to Dubai. Bandar Abbas airport outside Tehran was used for both civil and military flights. The Iranian airliner took off 27 minutes late. After take-off, an F14 fighter taxied and took off from the same airport.

All aircraft carry Identification, Friend or Foe (IFF) transmitters. The crew of the USS Vincennes initially registered a mode 3 (civil) signal from the flight however; the cursor was unintentionally left over the take off point on the radar screen on the Vincennes. The F14 transmitted a mode 2 (military) signal that the crew mistook for the airliner. They did not see the F14 as a separate aircraft.

The Vincennes crew had a timetable for the commercial flights from Bandar Abbas however, the times were not stated in local time and no flights were scheduled around this time of the day. They then assumed that since there was no commercial flight scheduled then the detected aircraft must be a military aircraft. The 27-minute delay was not significant in this evaluation.

Flight 655 set a course that took them towards the USS Vincennes at 300 knots. The crew of the Vincennes sent out a warning to the approaching aircraft however, the message they gave was to an aircraft flying at 350 knots the measured ground speed. Flight 655 was over Iranian territory, flying at an airspeed of 300 knots, and the flight crew most likely assumed the message was not directed to them. Several warning signals were sent without any reply. The USS Vincennes did not have the facility to hear radio messages on the civil aviation channels so could not monitor any calls between Flight 655 and air traffic control.

A few months before a US Navy vessel had been attacked by an Iraqi jet fighter in the Persian Gulf. The jet fired two Exocet missiles killing a number of US personnel and seriously damaging the vessel. The captain had been criticized for not protecting his vessel and had been reprimanded. The captain and crew of the Vincennes were well aware of this incident and its consequences.

The crew on the USS Vincennes were trying to resolve the issue of the mode 2 and 3 transmissions from the incoming aircraft. The last message to the captain was that the plane was transmitting a mode 3 signal so was most likely civilian. At this time, the radar operator stated that the plane was losing altitude, and taking up an attack position. The captain waited until the last minute and then ordered a firing solution. Two surface to air missiles were fired and one hit Flight 655 and the aircraft crashed killing all on board.

The official enquiry covered up the location of the USS Vincennes and the captain was cleared of any wrongdoing. He was in fact awarded a medal for protecting his ship. Another officer was given a commendation for good behaviour under fire.

Further investigation into the incident speculated that the captain of the USS Vincennes was known to be aggressive and had manoeuvred the vessel to deliberately provoke a hostile action. The crew were most likely preparing themselves for hostility and an engagement. When the aircraft was detected and the mode 2 signal noted the captain and crew started to behave as they had been trained to in aircraft attack exercises. When the captain was informed that the aircraft was most likely civilian he most likely already believed it was an Iranian F14. The USS Vincennes captain did not intend to make the same mistake as the captain on the US Navy vessel damaged by the Iraqi rockets. The message that the aircraft was descending was attributed to a phenomenon called 'scenario fulfilment'. Even though the information from the ships electronic log indicated the aircraft did not descend, the pressure and tension in the control centre caused people to adopt a scenario they had trained for many times. They started to live in the scenario and not real life. No one verified that the aircraft was actually descending towards the vessel. 'Confirmation bias' was a major factor in the way the captain and crew of the Vincennes interacted and acted.

Piper Alpha disaster July 1988

The inquiry into the Piper Alpha disaster found that the most likely source of the initial hydrocarbon release was a loose flange on discharge pipework from a condensate pump where the pressure safety valve (PSV) had been removed. A permit to work had been issued for the work. While the condensate pump was off line for the PSV inspection, other maintenance was carried out and a separate permit to work issued for this maintenance.

The duty condensate pump tripped and could not be restarted. The condensate pump that was out of service was required to maintain production. The lead operator prepared the standby condensate pump for operation and checked out that the maintenance work associated with the pump had been completed so that the isolation certificate could be signed out. He was probably unaware of the permit for the PSV that had been removed and replaced with a blind flange since this permit had been suspended before he came on shift. He believed it was safe to start the condensate pump.

The control of work practices on Piper Alpha were not in accordance with the written permit to work system. There were multiple tasks on single permits, poor control on isolations, inadequate verification of work sites and poor communication on permits at handover. These practices had become normalized and the safeguards that were intended to protect people were no longer in place. The process where incorrect and unacceptable practices become routine is normalization of deviance and this is a major factor in many major accidents.

The mechanical fitters that removed the PSV replaced it with a blind flange with bolts that were only hand tight since they planned to resume the work the next day. They may have believed that the pump could not be started since the permit had only been suspended hence the isolation certificate was still in operation to prevent the pump starting. Why spend time tightening up the bolts when they need to be taken off the next day. People will try to find easier ways to carry out their work and will put their trust in the permit to work system if it is convenient for them to do so. Even though the mechanics did not follow the procedures, they may have believed that their actions would not lead to a hydrocarbon leak.

The inquiry report into Piper Alpha criticized the management in Occidental, the operator of Piper Alpha, on their failure to ensure the permit to work system was functioning properly. There had been a number of incidents that indicated that the system was inadequate and corrective actions were not taken. The system that should have protected the lead operator and the mechanics from their incorrect beliefs and their very human errors was not functioning, as it should have been. The deviations in the permit to work system had become normalized.

Challenger Space Shuttle disaster January 1986

The propulsion system for the space shuttle launch consisted of the space shuttles own engines and two solid rocket booster (SRBs) connected to the external fuel tank that supplied the shuttles' engines. After each launch, the SRBs were recovered, inspected and refurbished.

NASA used a detailed and systematic process called a Flight Readiness Review (FRR) to ensure the launch could be carried out safely. The engineers in NASA and Thiokol, the SRB manufacturer, recommended a launch at the FRR prior to the launch of Challenger. NASA senior management accepted the recommendation as part of the FRR process. A problem with the 'O' rings on the joints of the SRBs was known and the engineers understood both the problem and how it had developed since its first indication at the second space shuttle launch. The problem had in fact been identified in an independent review of the SRBs in the shuttle design phase. The engineers believed that the risk to the space shuttle at launch was acceptable. It was normal that there were indications of leaks on the 'O' rings even to the point where the engineers could predict in advance how the 'O' rings would behave under certain launch conditions and with different testing of the SRB joints during assembly. The abnormal had been normalized within certain undefined limits. One of these undefined limits was the impact of temperature on the 'O' ring performance. That is, the engineers were aware that temperature could influence the 'O' ring performance but no test data was available to set any limits on ambient temperature at the time of launch.

The day before the scheduled launch the ambient temperature at the launch site was predicted to be around 2^{o} C. NASA asked for advice from their contractors on the impact of the predicted low temperatures on the space shuttle launch. The Thiokol engineers had previously noted a significant leak in an 'O' ring on a previous launch where the ambient temperature was 12^{0} C (53^{0} F). They had however dismissed any concern since this ambient temperature was out with the 'normal' ambient temperatures for the area and it was considered unlikely to reoccur for a space shuttle launch. On being informed of the potential low ambient temperature their belief on acceptable launch risk was challenged and they attempted to put together a technical argument to set the minimum launch temperature to 12^{0} C (53^{0} F). The Thiokol management initially recommended to delay the launch until the temperature was above 12^{0} C (53^{0} F). NASA accepted this recommendation however, the management at NASA criticized the quality of the technical argument on the temperature limitation and implied that it was not in accordance with their technical standards. Thiokol reviewed the technical argument and the Thiokol management changed their recommendation to launch as planned. NASA then considered that the original launch decision was confirmed and Challenger was launched at 11:38 am EST on the 28th January 1986. The film from the launch shows puffs of smoke released from a joint on the right SRB as it was ignited on the launch pad indicating a leak through ‘O’ rings. 65 seconds into the launch, at the point of greatest aerodynamic force on the shuttle, a flame was observed coming from the joint indicating the ‘O’ rings had failed. The flame burnt through the support for the SRB located on the external fuel tank, this disengaged the SRB and the resulting forces caused the space shuttle to explode after 73 seconds.

The process of normalization of deviance with regard to the ‘O’ ring failures was embedded in the NASA and Thiokol organizations. The problems with the ‘O’ rings had been analysed, studied and debated over many years and there was ‘hard data’ to justify the assessment of acceptable risk at launch. There were 24 successful launches before Challenger on the 28th January 1986 to confirm the risk was acceptable. The data presented by Thiokol to NASA the day before the launch was by comparison hastily put together, unclear and arguably inconclusive on the effect of temperature on the ‘O’ ring performance. The ‘gut feeling’ of the Thiokol engineers and their poorly constructed arguments were not enough when stacked against the hard data and experience. When normalization of deviance can affect a well-organized and technically competent organization like NASA then it should be a wakeup call for all organizations and hopefully give management a good dose of humility.

The NASA organization had communication processes and risk management processes that were followed in the run up to the Challenger disaster, the problem was related to the way the decision making process was made. Diane Vaughan in her book ‘The Challenger Launch Decision: Risky Technology, Culture and Deviance at NASA’ describes a process of normalization of deviance that is relevant to all hazardous industries with complex technology and a highly skilled workforce.

The organization recognized the problem with the ‘O’ rings and even recognized that the problem seemed to be getting worse over time. The organization also recognized that temperature could have an impact on the ‘O’ ring performance. The problems were discussed and analysed at the Flight Readiness Review (FRR). However, the highly technical Level 3 and 4 organisations continually increased their knowledge and understanding of the problems. Each new failure had a rational explanation and each new mitigation measure had a logic with a solid technical grounding. There was however, no perception of increasing risk as the problem developed. ‘O’ ring failures were normalized and each failure accounted for. Since the problem was not a new problem then there was no requirement to report the development of the ‘O’ ring problems to the level 1 and 2 management levels where the final launch decision was made.

The regulatory organisations, the internal Safety, Reliability, and Quality Assurance Program (SR&QA) and the external ‘The Aerospace Safety Advisory Panel’ were both dependent on the NASA organisation for information hence lacked a true independence in their evaluations. Reliance on an independent body that is not really independent can lead to a false sense of security and actually strengthen the normalization of deviance process.

How to influence incorrect beliefs?

Influencing incorrect beliefs requires both identifying them and changing them before they lead to actions that cause major accidents. The major accident examples above will hopefully convey two important messages. The first is that this is challenging and should not be underestimated. The second is that it is possible, there are often signs that the processes that create and maintain incorrect beliefs are in place and working, so they can be detected.

Four processes are suggested to addressing incorrect beliefs. Four process to ensure that ‘what we do know is actually so’.

These are:

- Dialogue
- Peer reviews
- Incident investigation
- Audits

Incident investigation and audit processes should already be place in organizations so the focus emphasized in this paper is how to use these effectively. Peer reviews may already be in place and the focus in this paper is to introduce peer reviews if they are not already in place and do more if they are in place. Many organisations would maintain that dialogue is a process that is ongoing and that occurs as a natural part of the operation or of doing business. Organisations often mistake communication for dialogue and fail to create an environment where dialogue thrives. Dialogue should be directed to understanding and problem solving and should be based on openness, honesty, and mutual commitment

Dialogue

Creating dialogue in normal work situations can challenge incorrect beliefs. David Marquet in his book ‘Turn the Ship Around’ describes a method that he terms as ‘deliberate action’ that is worth considering. Members of the crew of the Santa Fe nuclear submarine, where he was captain, were encouraged to say ‘I intend to …take an action..’ and then state the key assumptions that the action is based on. The people hearing the statement had an opportunity to intervene if the action and/or the assumptions were considered incorrect. Even a person hearing his own voice may realize the action and/or assumptions were flawed. The crew of the Santa Fe even adopted the technique when working alone with good success. What if the captain of the Boing 737 in the Kegworth air crash had said ‘I intend to shut down the right engine as I believe the smoke we are detecting in the cabin is due to the air conditioning coming from the right engine’. Maybe the first officer would have reacted to the assertion on the air-conditioning. If the captain had made this statement to the people in the cabin then maybe the people that noticed the fire in the left engine would have spoken up. At that time, the captain still had the opportunity to restart the right engine. Some of the survivors stated that they had seen the fire on the left engine but assumed the crew knew what they were doing.

Encouraging dialogue at risk assessments and similar meetings and processes to ensure everyone contributes. Leaders and facilitators need to set up the meetings firstly so that participants can contribute, and secondly so that they want to contribute. This requires a combination of structure and humility that accounts for the diversity of the participants, for example ensuring that participants are comfortable in the language that is to be used. No participant should leave a risk assessment without saying something.

'What if' scenarios are useful to challenge both conscious and unconscious knowledge. Team sessions can be set up where scenarios can be developed and discussed. Scenarios that lead to major accidents are particularly relevant as these are often exciting. Start with the major accident and work back to determine what would need to take place for this major accident to happen here. Then ask the question whether the sequence of events is realistic. Maintain a focus on how the major accident can happen here rather than how the major accident cannot happen here. Keep working the organisation round to the things that are not working and to revealing incorrect beliefs.

Using lessons learned from incidents, accidents and major accidents on a regular basis is a useful approach to challenge incorrect beliefs. The key to using lessons learned examples is the quality of the information used, e.g. data sheets, and the availability of this information for the organisation. Learning from major accidents seems sensible however, there are limitations in this approach as described by Smith, Roels and King in their paper 'Guidance on Learning from Incidents, Accidents and Events' presented at the IChemE Hazards 25 conference in 2015. Learning from others does not necessarily address the problems in one's own organisation.

Peer Reviews

Peer Reviews are useful to challenge the beliefs in an organisation. People often respond better to criticism and suggestions from their peers rather than from people that arguably do not really understand their problems. Participants in peer reviews tend to be more open and more willing to engage in dialogue. The peer review can lead to establishing best practices and communities of interest that continually share experience. Involvement in peer reviews often stimulates individuals to be more curious about their work place and work practices and become more open to suggestions from others on how to improve. Peer reviews that transverse different industries can give different insights and create more stimulating dialogue. Sellers, Mason and Hemming presented a paper at the IChemE Hazards XXI conference in 2009 and described a cross industry peer review process for control room operations. The peer review process was set up as response to a Health and Safety Executive conference in April 2008, *learning from the top – avoiding major incidents*. Their conclusion was that peer reviews could provide significant value to a wide range of safety critical industries. One point that the paper noted that is particularly relevant to 'what we do know, that isn't so' was the way the peer review process *fundamentally challenged the company's status quo*. The process is a 'bottom up' process that challenges beliefs and creates a great opportunity to find out if confirmation bias and normalization of deviation are waiting to contribute to a major accident.

Incident Investigation

Incident investigation is an essential process to highlight incorrect beliefs that lead to incorrect actions. Smith, Roels and King in their paper 'Guidance on Learning from Incidents, Accidents and Events' presented at the IChemE Hazards 25 conference in 2015 presented guidelines on Learning from Incidents that are useful and worth considering.

Incident investigation is a tremendous opportunity to learn and improve, however many incident investigations fail to uncover the reasons why there are incorrect beliefs in the organisation. They manage the 'what happened' and 'how it happened' but fail to find out 'why it happened'. One reason for this is that the terms of reference does not always ask the questions that would lead to the answers that are required.

The terms of reference for the investigation should include an assessment of whether confirmation bias and normalization of deviance, or other social processes, were evident and whether these were contributory factors to the causes of the incident. Investigators should be trained to recognize these processes.

Investigations into non-accidents can also be useful to find incorrect beliefs. A successful outcome is not necessarily an indication of a successful process. There may have been mistakes, misunderstandings or other faults that occurred during the activity that were rectified underway or the circumstances were such that an incident did not occur. Under different circumstances, the route to a successful outcome could end up in a major accident. Diane Vaughan suggests investigation of 'non-accidents' in her book on Challenger. Non-accident investigation can reveal hidden barriers and show how vulnerable the organisation is to changes in particular organisational changes.

Investigation into successful operations should also be carried out to identify best practices for carrying out activities. Understanding success and repeating success is an important factor in improving performance. If you do not know why you are successful then you may not be successful much longer. This includes success in prevention of major accidents.

One final point on incident investigation is how to address incorrect management beliefs. The terms of reference for an investigation is often signed off by a senior manager and is essentially a message to find out what they did and identify any improvements that they need to make. All terms of references should include a statement 'Find out what I (the senior manager who signs the terms of reference) could have done to prevent this incident'. Andrew Hopkins advocates that management should display 'mindful leadership'. 'Mindful leadership' means being constantly on the lookout for unsatisfactory conditions and behaviours, and for processes that are not functioning. 'Mindful leadership' requires displaying humility to encourage a response.

Auditing

Auditing is important to identify and address incorrect beliefs. Auditing on critical systems and processes, and follow up of actions identified from audits is essential to ensure these are functioning properly. Auditing should be carried out with people with expertise in the area to be audited but with an independence from the organisation.

Occidental did not have an audit system for the permit system on Piper Alpha. The offshore safety personnel were expected to check that system was functioning and the Occidental management assured themselves that the system was satisfactory using negative feedback. As long as I so not hear anything to the contrary then everything is OK.

David Marquet in his book 'Turn the Ship Around' recognized the resistance in the crew of the Santa Fe to audits and reviews. These were regarded as a nuisance that would probably result in extra work to follow up the findings. Marquet introduced the term 'embrace the audit' and encouraged his crew to see the audit as an opportunity to learn and improve. He coached his crew to ask the audit team questions and try to learn from the experienced people that came on board. This approach resulted in a significant improvement in the US Navy audit scoring system and contributed to Santa Fe being awarded 'best in class' submarine in the fleet for many years.

Audits should be set up to look for processes like confirmation bias and normalization of deviance in a similar way to incident investigation. Audit teams should include people that are familiar with processes like confirmation bias and normalisation of deviance and how to identify whether these are in place.

Would a truly independent audit of the space shuttle program, with a remit to specifically look for normalization of deviance have identified the increasing risks associated with the SRB 'O' ring and brought it to the attention of the NASA level 1 and 2 management before the Challenger launch?

Conclusion

The processes for the development and influence of individual and organisational knowledge and certainty need to be understood if an organization wants to protect itself from, action being taken based on incorrect beliefs. That is action based on 'what we do know that isn't so'. Two of the most important processes that result in incorrect beliefs are 'confirmation bias' and normalization of deviance'. Companies need to put in place systems that find out whether these processes are actually taking place in their organisations and how vulnerable they are to their effects.

There is a potential to use dialogue, peer reviews, incident investigation and audits for this purpose. All of these are used in industry today and are most likely in place in companies already. Incident investigations and audits need to be adapted to seek out beliefs that are incorrect and in particular look for 'confirmation bias' and 'normalization of deviance'. Peer reviews should be carried out more extensively and over a wider subject area to challenge established practices and identify incorrect beliefs. Company cultures need to adapt to improve dialogues that root out and challenge 'incorrect beliefs' at the individual and organisational levels.

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