Lessons from other industries

The development of safety culture in the nuclear industry

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Summary

This paper explores the development of the concept of nuclear safety culture by reference to four of the most significant nuclear disasters in history, i.e. Three Mile Island, Chernobyl, Tokai Mura, and Fukishima. Although the paper describes developments in the nuclear industry, the lessons learned can be applied to any high hazard industry and relate to:

- leadership
- the need for a questioning/challenge culture
- a learning culture
- safety considerations are central to any decision-making process

Keywords: Safety culture; nuclear

Introduction

I write this article from the perspective of having spent 35 years in the nuclear industry in various safety roles and at different levels within the industry. When I started in October 1977, it was only seven months after the last fatal accident to have occurred on the site I was working at. Tony Fishwick's article in LPB 239[1] describes what happened and analyses the causes of this tragic event. Over the several decades that have passed since that time, much has been said and written about the subject of safety culture. Given the circumstances of this accident, and the nature of the organisation at the time it occurred, I have asked myself, was there a pervading culture at that time which somehow contributed to this accident occurring? The same question can and should be asked of any major accident of course, and in this article, I have examined some major accidents from the nuclear industry with this question in mind.

Four accidents which had a major impact on the development of nuclear safety culture are described below. A theme common in these events is that problems were allowed to creep in over time. Had these problems been recognised, challenged, and resolved, the events could have been prevented or their severity mitigated. The series of decisions and actions that resulted in these events can usually be traced to the shared assumptions, values and beliefs of the organisation.

Three Mile Island

This accident occurred on 28 March 1979. It was initiated by a series of relatively minor and not unusual events which, through incorrect responses to them, resulted in the situation escalating into a partial melt down of the reactor core. Before going through the sequence of events which led to the accident, a brief description of the Three Mile Island Pressurised Water Reactor (TMI PWR) is given to help the reader follow the story.

Description of reactor

Figure 1 shows the basic design of the TMI PWR nuclear reactor[2]. In the Primary Cooling Circuit (PCC), there is a piece of equipment called the Pressurizer. The purpose of this vessel is to maintain the pressure inside the PCC at about the same level. Inside the Pressurizer is water with a bubble of steam above it. If the pressure in the PCC becomes too high, a valve called the Pilot Operated Relief Valve (PORV) opens automatically to relive the pressure. When the pressure is reduced to the correct level, the PORV closes, again automatically.

The accident

The sequence of events which led to the accident began when a number of pumps tripped in the secondary cooling circuit, which in turn caused the turbine to trip. Without the cooling effect of the secondary circuit, the temperature of the reactor began to rise rapidly and thus also the pressure. The reactor control system reacted automatically as it was designed to do, and the PORV opened to relieve the pressure in the PCC. This slowed the rate of pressure increase, but it soon reached the point where the reactor protection system initiated an emergency shutdown of the reactor. Without the heating effect of the nuclear reaction, the pressure in the PCC reduced to a point where the PORV should have automatically shut again. Unfortunately, the PORV remained stuck open, allowing steam and eventually coolant water to escape and the pressure in the reactor to continue to drop. Again, the reactor emergency system responded as it should have done, and High Pressure Injection Pumps forced cooling water into the reactor system. This had the effect of increasing the water level in the Pressurizer. The operators, not recognising that a Loss of Coolant Accident (LoCA) was occurring, responded by reducing the flow of replacement water. Their training told them that the pressurizer water level was the only dependable indication of the amount of cooling water in the system. Because the pressurizer level was increasing, they thought the reactor system was too full of water. Again, their training told them to do all they could to keep the pressurizer from filling with water. If it filled, they could not control pressure in the cooling system, and it might rupture.

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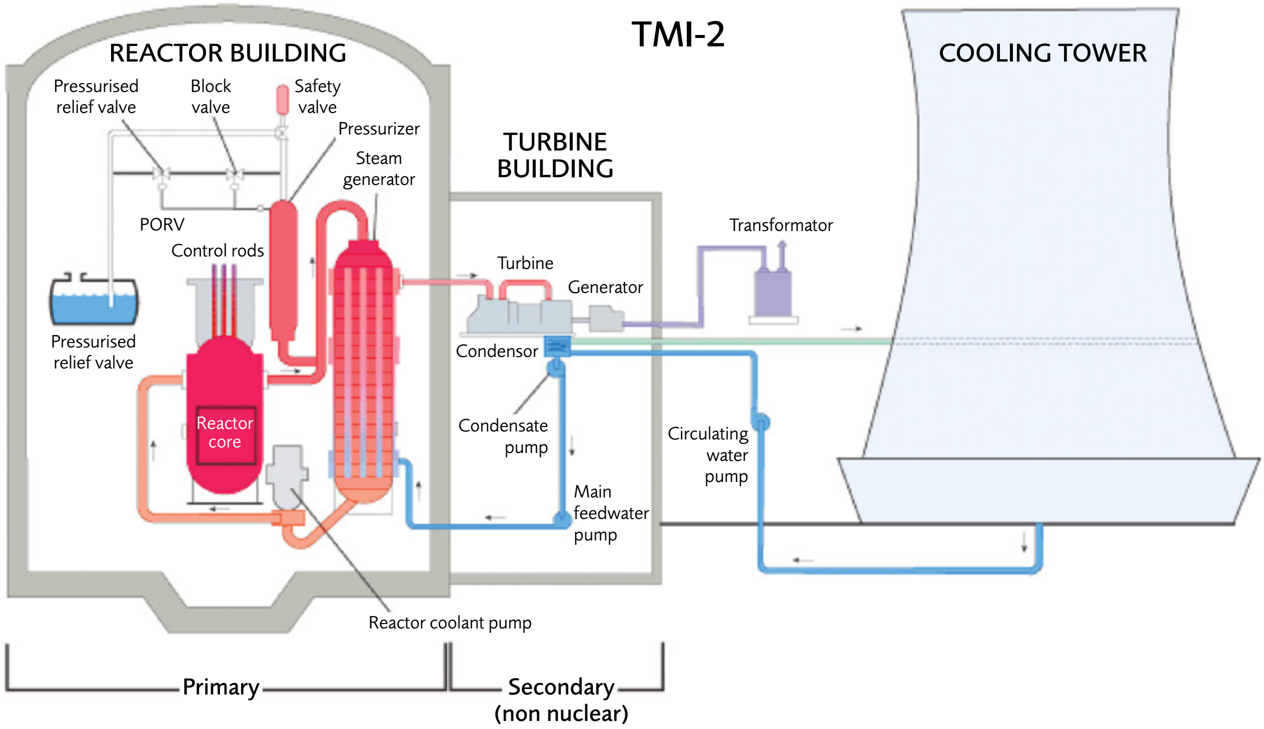

Figure1 – Schematic of the 3 Mile Island Pressurised Water Reactor

The lower pressure then resulted in steam forming in the PCC. Pumping a mixture of steam and water caused the reactor cooling pumps to vibrate, prompting the operators to shut down the pumps. This ended forced cooling of the reactor core. (The operators still believed the system was nearly full of water because the pressurizer level remained high.) However, as reactor coolant water boiled away, the reactor's fuel core was uncovered and became even hotter. The fuel rods were damaged and released radioactive material into the cooling water.

Chernobyl

This accident occurred on 26 April 1986. It is now well known as the worst nuclear disaster in history. The reactor design, the RBMK (Channelised Large Power Reactor) reactor was unique to the Soviet Union and embodied several design flaws which played a huge part in the disaster. The Soviet nuclear industry at the time of the disaster was one under huge pressure to deliver results. This too was a contributory factor.

A detailed technical explanation of the nature of the accident and its causes can be found in reference 3. In summary the accident was the disastrous outcome of a test which went catastrophically wrong. The test involved tripping one of its turbines and determining how long the coolant pumps could be operated by the remaining inertia of the turbine. It was hoped that this would be sufficient for the minute or so it took for the emergency generators to turn on and reach full power. In order for the test to begin, the reactor had to be in a low power state and with its emergency cooling system (ECS) switched off. An unexpected delay in the commencement of the test had led to the build-up of a neutron poison called xenon (a naturally occurring inert gas). In order to counter this effect, the operators withdrew more control rods than the station's operating rules allowed. This effect of this was to leave the reactor in a perilously unstable state, one in which any slight variation in reactor conditions could cause a runaway nuclear reaction leading to a massive power spike. There is uncertainty about exactly what caused it, but this is exactly what happened.

Tokai Mura

This accident occurred on 30 September 1999 in a small fuel preparation plant operated by JCO (formerly Japan Nuclear Fuel Conversion Co.), a subsidiary of Sumitomo Metal Mining Co. The plant supplied material to various specialised research and experimental reactors and was not part of the electricity production fuel cycle.

A detailed account of the accident can be found in reference 6. For the purposes of this article, it is sufficient to say that a process to dissolve batches of triuranium octoxide (U3O8) with nitric acid was being carried out at the facility. The authorised process and the unauthorised modification to the process, the 'executed' process, are shown in Figure 2. The modified process had two modifications to the authorised process. The first was that 10l buckets were used to dissolve the U3O8 instead of the dissolver vessel. Secondly, and the much more serious procedural departure, was the transfer of the U3O8 solution into a non-safe by shape precipitation vessel. The reason the operators chose to modify the process was that it was difficult to fit the transport flasks underneath the safe by shape dispensing vessel. Adopting the modified method was easier and speeded up the operation.

Two operators commenced dissolving batches of U3O8 and pouring the resultant solution into the precipitation vessel. Whilst pouring the seventh batch the contents went critical. Sadly, the two operators eventually died as a result of the radiation doses they received.

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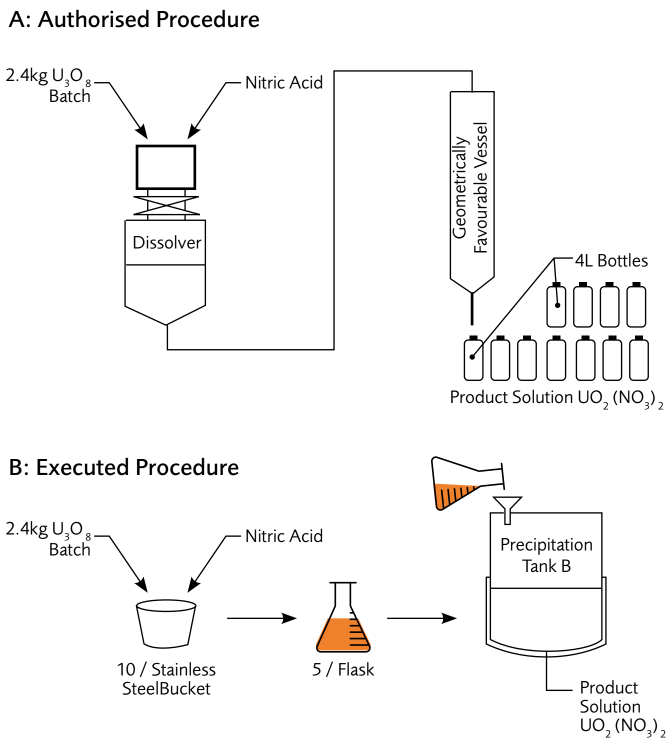

Figure 2 – The authorised and modified dissolution and dispensing processes

Fukushima

On 11 March 2011, Japan recorded its strongest ever earthquake. Reactors close to the earthquake, including those operating at Fukushima Daiichi, shut down as designed (see reference 4 for a full description of the disaster).

However, due to insufficient sea defences, the Fukushima Daiichi plant's backup generators, which were meant to pump cooling water through the reactor, were destroyed by the 15m tsunami. As a result, the cores of units 1-3 largely melted over the following three days, and the accumulation of hydrogen produced by the reaction of the hot fuel cladding with water resulted in several hydrogen explosions in units 1, 2 and 4.

More than anything, this disaster showed the importance of thoroughly assessing naturally occurring events and taking appropriate action when found to be credible. The investigation committee commissioned by the Japanese Government[5] concluded that 'the government and TEPCO failed to prevent the disaster not because a large tsunami was unanticipated, but because they were reluctant to invest time, effort and money in protecting against a natural disaster considered to be unlikely.'

Summary of safety culture lessons learned

The accidents described above bring into sharp focus how a poor safety culture can lead to the most catastrophic consequences. The key lessons which emerge from the above four accidents are discussed below.

Leadership

It cannot be overemphasised that a healthy nuclear safety culture will not be achieved without the full and credible commitment of the CEO and board of an organisation. It is they who, through their own behaviour and priorities, lay the foundations for a healthy and sustainable nuclear safety culture. This must be reinforced by a positive and visible commitment to safety through the management chain. The shortcomings in organisational nuclear safety culture evident in the accidents described above, can all ultimately be put down to senior management failing to establish and promote this.[1]

The need for a questioning/challenge culture

In all four examples, there was an underlying belief that major accidents could not happen at these plants. There was clearly a level of complacency in all four organisations. In the case of Fukushima for example, this assumption was accepted by nuclear power plant operators and was not challenged by regulators or by the Government. As a result, Japan was not sufficiently prepared for the severe nuclear accident triggered by natural events. In particular, it was believed that there was sufficient redundancy in having back up diesel generators. But no thought had been given to emergency arrangements should these fail.

Similarly, there was a mind-set at all levels within JCO, the company operating the Tokai Mura facility, and the regulatory authority that a criticality accident was not a credible event. This mind-set resulted in an inadequate review of procedures, plans, equipment layout, human factors, etc. by both the company and the licensing officials.

In the case of TMI, the Presidents Commission found that: 'The fundamental problems which led to the accident were not equipment, but people related. Since the nuclear industry had run for many years without a serious incident, a belief had turned into a conviction that nuclear power plants were sufficiently safe. They stated that 'The most serious "mindset" is the preoccupation of everyone with the safety of equipment, resulting in the downplaying of the importance of the human element in nuclear power generation.'

A questioning/challenge culture is a core requirement if safety is to be at the heart of an organisation. A relatively simple process such as STAR - Stop, Think, Act, Review, can be very helpful in addressing unusual situations which may arise. An organisation should be constantly on the lookout for examples of good practice which can be shared with the workforce.

A formal process has been developed in the nuclear industry to enhance the challenge culture, namely the Independent Oversight Process[7]. This is a function which is independent from all other parts of the business. It carries out proactive and reactive assessments to gauge the health of the organisation's Safety Management Systems (SMSs). Reports are routinely prepared for senior levels of the organisation.

A learning culture

Both TMI and Chernobyl were particularly lacking in this respect.

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[1] *It must be noted here, that if a state is so intent on achieving a specific goal in a certain time frame, as was the case in the Chernobyl disaster, it will be extremely difficult, if not impossible for an organisation to embrace all the traits of a healthy nuclear safety culture.*

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The Presidents TMI Commission[7] found 'previous accidents had occurred which bore a striking resemblance to TMI. An opportunity was missed to learn from these accidents, and to produce new clear instructions for the operators.'

In the case of the Chernobyl accident, two earlier accidents at RBMK reactors, one at Leningrad (Unit 1 in 1975) and a fuel failure at Chernobyl (Unit 1 in 1982), had already indicated major weaknesses in the characteristics and operation of RBMK units. Because of lack of communication and lack of exchange of information between the different operating organisations, the operating staff at Chernobyl were not aware of the nature and causes of the accident at Leningrad Unit 1. Similarly, the flaw in the design of the fuel rods had been picked up at the Ignalina plant in 1983. However, no correction was made following this discovery, no compensatory measures were taken and any dissemination of information to operating organisations was not followed up.

An effective, formalised learning from experience process is an essential component of an SMS. To be fully effective, this must:

- Search for opportunities to improve both from inside and outside the organisation; and
- Positively encourage employees to report anomalies and management to respond to them in a timely fashion.

Safety considerations are central to any decision-making process

The Chernobyl and Tokai Mura disasters show organisations where this was particularly lacking. As noted above, operators of the Chernobyl plant were under huge pressure to deliver results. This probably gave rise to the mindset which was clearly evident in the operators' decision-making process. In particular, the decision to blindly forge ahead with the experiment, ignoring operating rules, significantly contributed to the onset of the disaster.

A similar mindset was very evident in the Tokai Mura incident, where there were company pressures to operate more efficiently. Consequently, unauthorised changes were made to approved process which led directly to the criticality excursion.

Safety must be at the centre of any decision making. For this to be achieved, an understanding of the effect decisions have on safety requires a complete understanding of the characteristics of a plant in normal and abnormal conditions. In the case of TMI, the Commission concluded that the operators were unable to quickly diagnose the precise nature of the problem they were faced with because:

- The training of the operators was greatly deficient. It focussed primarily on operating the plant under normal conditions. The depth of understanding of even some of the senior reactor operators left them ill-prepared to deal with something as confusing as the circumstances in which they found themselves.
- The plant control room, whilst probably adequate for controlling normal operations, was seriously deficient when it came to dealing with emergency situations. The Commission found that 'little attention had been paid to the interaction between human beings and machines under the rapidly changing and confusing circumstances of an accident.'

Additionally, the TMI report[8] found 'A preoccupation with rules and regulations. A "mind set" existed that meeting the hugely complex set of regulations would guarantee safety, rather than having an absorbing concern with safety that will bring about safety'. Similarly, the Chernobyl report found that 'the poor quality of operating procedures and instructions, and their conflicting character, put a heavy burden on the operating crew, including the Chief Engineer.'

A thorough understanding of a plant comes from a thorough safety analysis. Only then can a comprehensive set of operating instructions be prepared on which to base operator training and monitor compliance.

All employees must recognise that they have a personal responsibility for their own safety and that of their colleagues. A fundamental part of this is those in a leadership position continually demonstrating their commitment to safety through their own messages and behaviours. Any opportunity to do this should be seized upon. It is important to stress that this must include everyone in a leadership position, CEO, managers, supervisors and staff representatives.

Nuclear safety culture development

The learning from these incidents, plus others that have occurred at nuclear facilities, have led to the development of comprehensive guidance on the key characteristics, or traits that are required to deliver an effective nuclear safety culture. Nuclear institutions such as the World Association of Nuclear Operators (WANO)[9], the Institute of Nuclear Power Operators (INPO)[10] and the International Atomic Energy Agency (IAEA)[11], have all produced their own detailed guidance. Various definitions have emerged which try to capture the definition of a safety culture. Examples from the above three organisations are:

The assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance. (IAEA).

The core values and behaviours resulting from a collective commitment by leaders and individuals to emphasise safety over competing goals, to ensure protection of people and the environment. (WANO).

An organisation's values and behaviours, modelled by its leaders and internalised by its members, that serve to make nuclear safety the overriding priority. (INPO).

All these organisations have a broadly similar approach to defining the characteristics or traits of a healthy safety culture. In addition to those already noted above, others which have emerged are described as follows:

- Respectful work environment: A high level of trust is established in the organisation, in part fostered through timely and accurate communication. Differing professional opinions are encouraged, discussed and resolved in a timely manner. Employees are informed of steps taken in response to their concerns.
- Continuous learning: Operating experience is highly valued and the capacity to learn from experience is well

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developed. Self-assessments, training and benchmarking are used to stimulate learning and improve performance. Nuclear safety is kept under constant scrutiny through a variety of monitoring techniques, some of which provide an independent or fresh perspective.

- **Problem identification and resolution:** Issues potentially impacting safety are promptly identified, fully evaluated and promptly addressed and corrected, commensurate with their significance. Identification and resolution of a broad spectrum of problems, including organisational issues, are used to strengthen nuclear safety and improve performance.
- **Environment for raising concerns:** A safety-conscious work environment is maintained where personnel feel free to raise nuclear safety concerns without fear of retaliation, intimidation, harassment or discrimination. Station managers create, maintain and periodically evaluate policies and processes that allow personnel to freely raise such concerns.

Conclusion

The development of the concept of nuclear safety culture has been described by reference to four of the most significant nuclear disasters in history. Whilst this article uses the term nuclear safety culture, even the most casual observer will see that all the culture traits are directly applicable to any high hazard industry. To emphasise this point, a second paper has been prepared which examines significant non-radiological events that have occurred on nuclear sites[12].

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