Incident

Three Mile Island – Can we learn from a nuclear accident that occurred 45 years ago?

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Summary

This article is written on the 45th anniversary of the Three Mile Island accident of March 28, 1979. It was the most serious accident in U.S. commercial nuclear power plant operating history, although its small radioactive release had no detectable health effects on plant workers or the public. Its aftermath brought about extensive changes involving emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations. It also caused the U.S. Nuclear Regulatory Regime (NRC) to strengthen its regulatory oversight. This paper highlights the main events leading to the accidents and the learnings that could still be valid almost half a century later. The paper does not intend to cover all failures and findings from the event, but it highlights tragic events from other industries which have common features with this nuclear accident.

Keywords: Nuclear, design, control room, alarms, normalisation of deviance, operator skills, learning from past events

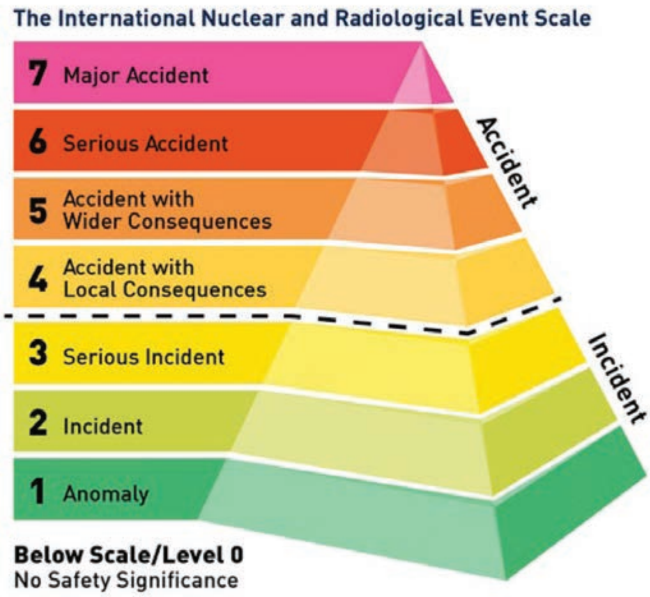

Figure 1 – The INES scale (Source: NRC.gov)

Introduction

The official investigation report[1] on the Three Mile Island Unit 2 (TMI-2) reactor partial meltdown reads like a well-written novel. The three-part document provides a clear description of what happened, starting early in the morning on 28th March 1979, in a way that almost feels like the screenplay of a movie. And I am not talking about the film "China Syndrome" which was being introduced in theatres all over the country just before the TMI-2 event. The plot of the movie involved an accident at a fictional nuclear power plant with impressive technical details based on past nuclear events. Despite the proud statement made by the plant management of Three Mile Island that such an event could never occur, a real-life nuclear reactor partial meltdown accident happened just twelve days later.

What happened in the plant?

The Three Mile Island accident was a partial nuclear meltdown of the Unit 2 reactor (TMI-2) of the Three Mile Island Nuclear Generating Station on the Susquehanna River in Londonderry Township, near the city of Harrisburg, Pennsylvania. The reactor accident began at 4:00 a.m. on March 28, 1979, and released radioactive gases and radioactive iodine into the environment. On the seven-point logarithmic International Nuclear Event Scale (INES), the TMI-2 reactor accident was rated Level 5, which means an "Accident with Wider Consequences" (Figure 1).

The accident started with failures in the non-nuclear secondary system followed by a stuck-open pilot-operated relief valve (PORV) in the primary system that allowed large amounts of water to escape from the pressurized isolated coolant loop. Plant operators failed to recognize the situation as a loss-of-coolant accident (LOCA). Loss of cooling capacity in a nuclear power generation plant is one of the worst-case scenarios. In the chemical industry, a similar, but much smaller scale accident would be such as losing the cooling capacity in an exothermic chemical reaction and being unable to stop the reaction before it reaches the point of an exothermic runaway reaction and explosion.

TMI training and operating procedures left operators and management ill-prepared for the deteriorating situation resulting from the loss of coolant. Poor control design, the use of multiple, similar alarms, and a failure of the equipment to clearly indicate either the coolant-inventory level or the position of the stuck-open PORV all led to a worsening LOCA. Let's take a look at these failures by investigating the sequence of events.

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Sequence of events

Figure 2 shows a schematic diagram of the plant to explain the series of events on 28 March 1979.

The event started with either a mechanical or electrical failure in the secondary, non-nuclear system of the plant. From the investigation report, a resin plug probably prevented the main feedwater pumps from sending water to the steam generators that remove heat from the reactor core. This caused the plant's turbine-generator and then the reactor itself to automatically shut down, immediately causing the pressure in the primary system to increase. To control that pressure, the PORV opened. It was located at the top of the pressuriser. The valve should have closed when the pressure fell to normal levels, but it became stuck open. Instruments in the control room, however, indicated to the plant staff that the valve was closed. As a result, the operators were unaware that cooling water in the form of steam was pouring out of the stuck-open valve. As alarms rang and warning lights flashed, the operators did not realise that the plant was already experiencing a LOCA.

Other instruments available to plant staff provided inadequate or misleading information. During normal operations, the large pressure vessel that held the reactor core was always filled to the top with water — according to the design at the time "there was no need for a water-level instrument to show whether water in the vessel covered the core". Consequently, operators assumed that if instruments showed that the pressuriser water level was high enough, it meant that the core was properly covered with water, but that was not the case.

Unaware of the stuck-open relief valve and unable to tell if the core was covered with cooling water, the staff took a series of actions that made the situation worse. The stuck valve reduced the pressure in the primary system to a level where the reactor coolant pumps started to vibrate and were turned off. The emergency cooling water being pumped into the primary system threatened to fill up the pressurizer completely—an undesirable condition—to prevent this, operators decided to override the automatic system and cut back on the flow of water. Without the reactor coolant pumps circulating water and with the primary system lacking emergency cooling water, the water level in the pressure vessel dropped and the core overheated. As the primary coolant drained away that the residual decay heat in the reactor core was not removed. The core suffered severe damage as a result.

Health effects

Given the nature of the plant, this nuclear accident caused concerns about the possibility of radiation-induced health effects, principally cancer, in the area surrounding the plant. Therefore, the Pennsylvania Department of Health maintained a registry for 18 years monitoring more than 30,000 people who lived within five miles of Three Mile Island at the time of the accident. The state's registry was finished in mid 1997, without any evidence of unusual health trends in the area. In addition, a number of independent health studies of the event showed no evidence of any abnormal number of cancers around TMI years after the accident. The only detectable effect was psychological stress during and shortly after the accident, not helped by the China Syndrome movie or the fact that residents around the plant had never been informed of potential accident scenarios or health effects before the accident. Media has its acceleration effect in case of tragic or frightening events. People perceive nuclear power energy

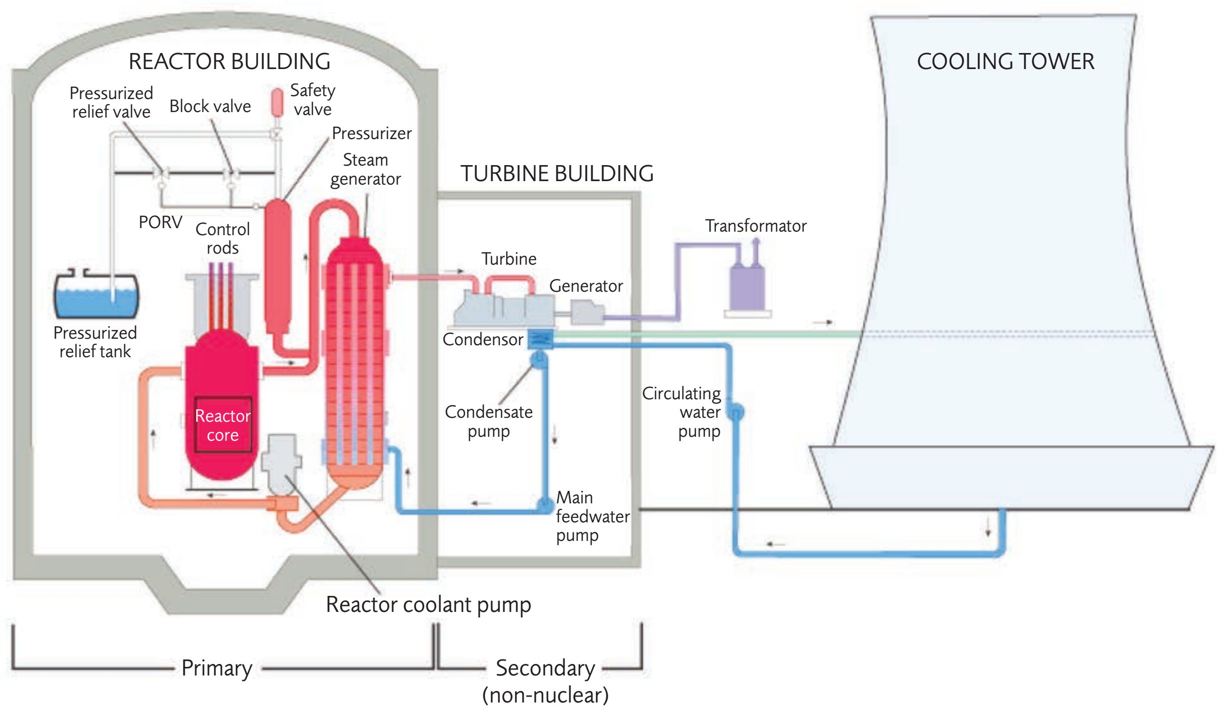

Figure 2–Schematic diagram of the plant[2]

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production and nuclear waste disposal as high-risk activities because the worst case consequences of a loss of control could have such catastrophic long term consequences.

Underlying factors

Before analysing the contributing factors to this event, it is worth mentioning the underlying conditions of the Unit-2. This unit was started up one year before the accident and had experienced a series of minor but troublesome mishaps. The unit went into commercial operation on 30 December in 1978 (3 months before the accident) and as stated in the investigation report, it "had been running reasonably well since".

Some of the major failures and learning points are discussed, without presenting all failures that caused the accident. These points are useful findings when compared them with more recent industrial accidents.

PORV

The PORV was a safety critical equipment to control the pressure. Operators in the control room failed to recognise that the PORV on the reactor pressurizer had not automatically closed, as it was designed to do, during recovery from a reactor trip. How could this happen? The failure to notice the open PORV can be traced to a misleading instrument that indicated the valve's position via a single red PORV status indicator light. This light was on when an electrical signal was sent to open the PORV, and it was off when the signal was terminated. However, the light did not indicate the actual position of the valve. As a result, when the PORV indicator light went out, the operators believed the valve had closed when in fact, it had stuck open. The investigation report noted that a valve indicator system that can directly sense the open and closed positions of the valve, i.e., a microswitch installed on the relief valve stem, would have shown the operators if the valve was open or closed.

A similar situation arose in the Flooding and capsize of ro-ro passenger ferry Herald of Free Enterprise with loss of 193 lives when the lack of indicator lights meant that the crew didn't know if the bow doors were open or closed.

Design issues

There were design issues relating to the PORV, as originally, the TMI-2 control room design contained no indicator light. The investigation found several other design issues that the investigators believed to have contributed to the accident. For example, inadequate control room design which included illogical panel layout, confusing use of indicator colour coding (Christmas tree effect) or difficulty for operators to read the meters, obscured displays (vertical panels behind the benchboard contained about 1900 displays, including indicator lights), labelling on back panels was difficult or impossible to read from main operating positions together with poor lighting combined to make even routine work difficult, not to mention the extreme difficulty during a nuclear emergency situation. Communication was hampered by the so-called "paging system" which had the tonal quality of a "bad bronchial cough", making communication very challenging.

Alarms

The control room contained more than 750 alarms which were not prioritised, and many were difficult to read from normal operator positions. In fact, during the first few minutes, over 100 alarms went off. The alarms were received so rapidly that the implications of each alarm could not be analysed in detail.

Issues reported by operators before the accident

Problems with the poorly designed alarm systems were reported by an operator.

On 23 April, 1978 an operator documented problems experienced during a reactor trip; he wrote a letter to his supervisor, expressing concerns about mechanical failures, poor system designs and improperly prepared control system coupled with improper operator training and inadequate emergency procedures.

These underlying factors mirror those in a number of past accidents, such as Milford Haven explosion in 1994, the Longford accident in 1998, Piper Alpha in 1988 and the Texas City explosion in 2005.

Normalisation of deviance

Operators seemed to be conditioned to expect problems in the secondary (non-nuclear) circuit rather than the primary system. Water discharged from the pressuriser via the PORV was collected in the reactor coolant drain tank. That means, when the PORV got stuck open, the water level in the tank rose. One of the valves, possibly the PORV had been leaking into the drain tank since autumn of 1978 and had been scheduled for maintenance during the next reactor shutdown. The leaking was known to operators and elevated level of water, high temperature and pressure in the drain tank was not an unusual observation to them. In fact, about once every shift, operators had been forced to pump the accumulated water from the drain tank. In addition, the instrumentation only gave instantaneous information about the level of water in the tank without recording the parameters. Alarms associated with the tank were behind the control panel and difficult to observe.

Other accidents where normalisation of deviance - "the gradual process through which unacceptable practice or standards become acceptable" was a key contributor to the event include the Challenger disaster in 1986, the Space Shuttle Columbia tragedy in 2003 or the gas plant explosion at Longford in 1998, the capsizing of an Italian cruise ship Costa Concordia in 2012, and the Royal Air Force Nimrod crash in 2006.

Skills of operators

In the case of TMI, many operators were recruited from the Navy, and these veterans were accustomed to nuclear submarines which were significantly smaller than any commercial nuclear power plant. The significant differences in Navy nuclear propulsion plants and civilian nuclear power plants suggested that personnel who may be highly qualified to operate Navy plants may not be the most qualified to operate large, complex commercial civilian nuclear plants. As the investigation revealed, "there was a significant effort to simplify system design to give confidence in the ability of operators to operate the plant properly". In fact, designers of commercial

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nuclear plants assumed that the operators were only a backup to the automatic control.

Lack of learning from past events

As the investigation revealed, there were a lot of so-called "precursor events" that would have served as learning points but not considered by the management of the TMI plant. For example, one of the most significant events similar to the TMI-2 accident occurred on 24 September, 1977 at the Davis-Besse nuclear power station in Ohio, where the relief valve for the reactor pressurizer failed to close when the reactor, running at only 9% power, shut down because of a disruption in the feedwater system.

The failure to learn lessons from previous accidents lead to repeat disasters, for example ammonium-nitrate fertiliser explosions starting with Oppau in 1921, then Texas City disaster in 1947, the Toulouse accident in 2001, West Texas explosion in 2013, Tianjin explosion in 2015 until the most recent accident in Beirut in 2020.

This paper discusses only a few learning points from the TMI-2 accident without detailing all the failures revealed by the investigation. The aim of this paper is to highlight the fact that most findings from a nuclear accident that occurred 45 years ago are still valid today and the investigation report is worth revisiting for experts not only from the nuclear but all other industries, too. The examples of past accidents which showed similarities in one way, or another serve as a reminder to demonstrate how important it is to keep the memory of past accidents alive and think beyond the fence of our own operations to learn and improve.

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