SAFETY AND SECURITY

Three Mile Island Accident

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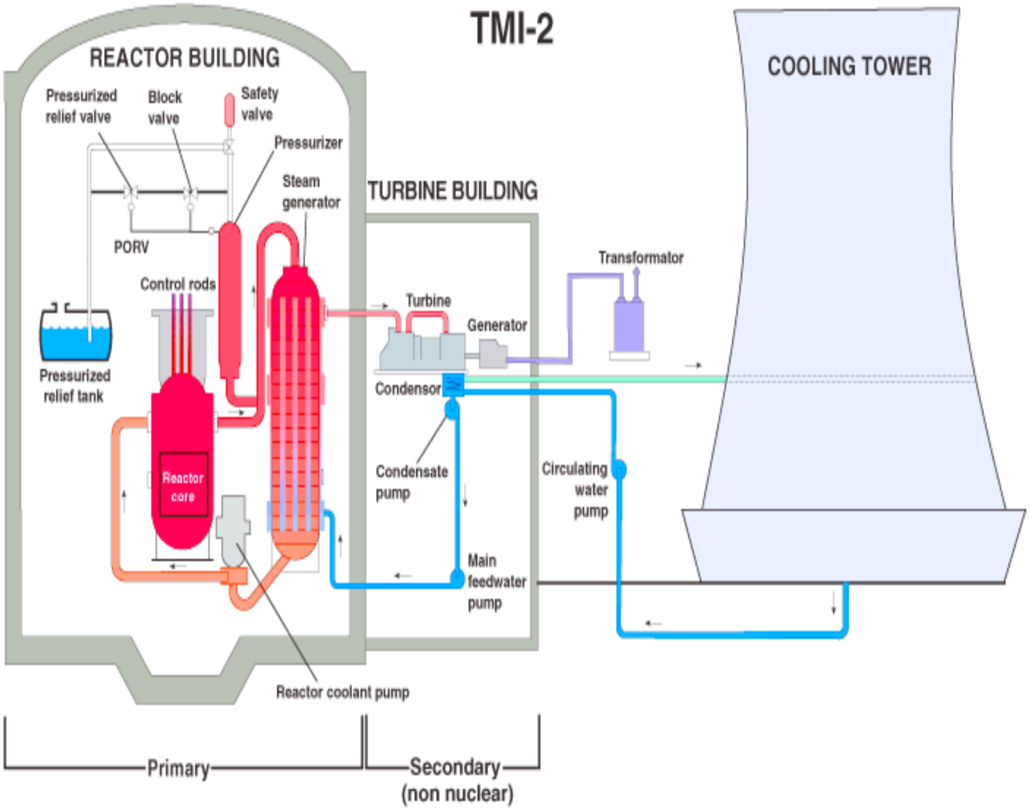
- In 1979 at Three Mile Island nuclear power plant in USA a cooling malfunction caused part of the core to melt in the #2 reactor. The TMI-2 reactor was destroyed.
- Some radioactive gas was released a couple of days after the accident, but not enough to cause any dose above background levels to local residents.
- There were no injuries or adverse health effects from the Three Mile Island accident.

The Three Mile Island power station is near Harrisburg, Pennsylvania in the USA. It had two pressurized water reactors. TMI-1, a PWR of 880 MWe (819 MWe net) entered service in 1974, and remained one of the best-performing units in the USA until it was shut down in 2019. TMI-2 was of 959 MWe (880 MWe net) and almost brand new at the time of the accident.



The accident to unit 2 happened at 4 am on 28 March 1979 when the reactor was operating at 97% power. It involved a relatively minor malfunction in the secondary cooling circuit which caused the temperature in the primary coolant to rise. This in turn caused the reactor to shut down automatically. Shut down took about one second. At this point a relief valve failed to close, but instrumentation did not reveal the fact, and so much of 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.

The operators were unable to diagnose or respond properly to the unplanned automatic shutdown of the reactor. Deficient control room instrumentation and inadequate emergency response training proved to be root causes of the accident.

The chain of events during the Three Mile Island accident

Within seconds of the shutdown, the pilot-operated relief valve (PORV) on the reactor cooling system opened, as it was supposed to. About 10 seconds later it should have closed. But it remained open, leaking vital reactor coolant water to the reactor coolant drain tank. The operators believed the relief valve had shut because instruments showed them that a "close" signal was sent to the valve. However, they did not have an instrument indicating the valve's actual position.

Responding to the loss of cooling water, high-pressure injection pumps automatically pushed replacement water into the reactor system. As water and steam escaped through the relief valve, cooling water surged into the pressurizer, raising the water level in it. (The pressurizer is a tank which is part of the primary reactor cooling system, maintaining proper pressure in the system. The relief valve is located on the pressurizer. In a PWR like TMI-2, water in the primary cooling system around the core is kept under very high pressure to keep it from boiling.)

Operators 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. 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.

Steam then formed in the reactor primary cooling system. Pumping a mixture of steam and water caused the reactor cooling pumps to vibrate. Because the severe vibrations could have damaged the pumps and made them unusable, operators 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.

At 6:22 am operators closed a block valve between the relief valve and the pressurizer. This action stopped the loss of coolant water through the relief valve. However, superheated steam and gases blocked the flow of water through the core cooling system.

Throughout the morning, operators attempted to force more water into the reactor system to condense steam bubbles that they believed were blocking the flow of cooling water. During the afternoon, operators attempted to decrease the pressure in the reactor system to allow a low pressure cooling system to be used and emergency water supplies to be put into the system.

Cooling restored, radioactive releases to air

By late afternoon, operators began high-pressure injection of water into the reactor cooling system to increase pressure and to collapse steam bubbles. By 7:50 pm on 28 March, they restored forced cooling of the reactor core when they were able to restart one reactor coolant pump. They had condensed steam so that the pump could run without severe vibrations.

Radioactive gases from the reactor cooling system built up in the makeup tank in the auxiliary building. During March 29 and 30, operators used a system of pipes and compressors to move the gas to waste gas decay tanks. The compressors leaked, and some radioactive gases were released to the environment. These went through high-efficiency particulate air (HEPA) filters and charcoal filters which removed most of the radionuclides, except for the noble gases, the estimated total of which was about 370 PBq (the Kemeny Commission said "a maximum of 480 PBq noble gases" and the Nuclear Regulatory Commission (NRC) also quotes 1.6 PBq of krypton release in July). With short half-life and being biologically inert, these did not pose a health hazard.

The hydrogen bubble

When the reactor's core was uncovered, on the morning of 28 March, a high-temperature chemical reaction between water and the zircaloy metal tubes holding the nuclear fuel pellets had created hydrogen gas. In the afternoon of 28 March, a sudden rise in reactor building pressure shown by the control room instruments indicated a hydrogen burn had occurred. Hydrogen gas also gathered at the top of the reactor vessel.

From 30 March through 1 April operators removed this hydrogen gas 'bubble' by periodically opening the vent valve on the reactor cooling system pressurizer. For a time, NRC officials believed the hydrogen bubble could explode, though such an explosion was never possible since there was not enough oxygen in the system.

Cold shutdown and investigation

After an anxious month, on 27 April operators established natural convection circulation of coolant. The reactor core was being cooled by the natural movement of water rather than by mechanical pumping. The plant was in "cold shutdown", i.e. with the water at less than 100°C at atmospheric pressure.

The head of the reactor pressure vessel was removed in July 1984 allowing access to the remains of the core. Subsequent investigation revealed that at least 45% of the core – 62 tonnes – had melted and 19 tonnes of this had ended up in the lower plenum, mostly in the lower head of the reactor pressure vessel, but without seriously damaging the vessel. Most of the melted core material (corium) had remained in the core region. In 1988 a multinational OECD Vessel Investigation Project (VIP) took samples to evaluate the situation in detail and confirmed that there was much less damage than anticipated.

Public concern and confusion

When the TMI-2 accident is recalled, it is often in the context of what happened on Friday and Saturday, March 30-31. The drama of the TMI-2 accident-induced fear, stress and confusion on those two days. The atmosphere then, and the reasons for it, are described well in the book "*Crisis Contained, The Department of Energy at Three Mile Island*," by Philip L Cantelon and Robert C. Williams, 1982. This is an official history of the Department of Energy's role during the accident.

"Friday appears to have become a turning point in the history of the accident because of two events: the sudden rise in reactor pressure shown by control room instruments on Wednesday afternoon (the "hydrogen burn") which suggested a hydrogen explosion? became known to the Nuclear Regulatory Commission [that day]; and the deliberate venting of radioactive gases from the plant Friday morning which produced a reading of 1,200 millirems (12 mSv) directly above the stack of the auxiliary building.

"What made these significant was a series of misunderstandings caused, in part, by problems of communication within various state and federal agencies. Because of confused telephone conversations between people uninformed about the plant's status, officials concluded that the 1,200 millirems (12 mSv) reading was an off-site reading. They also believed that another hydrogen explosion was possible, that the Nuclear Regulatory Commission had ordered evacuation and that a meltdown was conceivable.

"Garbled communications reported by the media generated a debate over evacuation. Whether or not there were evacuation plans soon became academic. What happened on Friday was not a planned evacuation but a weekend exodus based not on what was actually happening at Three Mile Island but on what government officials and the media imagined might happen. On Friday confused communications created the politics of fear." (Page 50)

Throughout the book, Cantelon and Williams note that hundreds of environmental samples were taken around TMI during the accident period by the Department of Energy (which had the lead sampling role) or the then-Pennsylvania Department of Environmental Resources. But there were no unusually high readings, except for noble gases, and virtually no iodine. Readings were far below health limits. Yet a political storm was raging based on confusion and misinformation.

Health impacts of the accident

The Three Mile Island accident caused concerns about the possibility of radiation-induced health effects, principally cancer, in the area surrounding the plant. Because of those concerns, the Pennsylvania Department of Health for 18 years maintained a registry of 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 discontinued in mid 1997, without any evidence of unusual health trends in the area.

Indeed, more than a dozen major, independent health studies of the accident 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.

The studies found that the radiation releases during the accident were minimal, well below any levels that have been associated with health effects from radiation exposure. The average radiation dose to people living within 10 miles of the plant was 0.08 millisieverts (mSv), with no more than 1 mSv to any single individual. The level of 0.08 mSv is about equal to a chest X-ray, and 1 mSv is about one-third of the average background level of radiation received by US citizens in a year. In order for the lifetime risk of developing cancer to increase even slightly, doses above 100 mSv during a very short time frame would be required. A dose of 100 mSv would increase lifetime cancer risk by approximately 0.4%, to be compared with the 38-40% of all US citizens who would develop cancer at some point during their life from all other causes.

In June 1996, 17 years after the TMI-2 accident, Harrisburg US District Court Judge Sylvia Rambo dismissed a class action lawsuit alleging that the accident caused health effects. The plaintiffs appealed, but the judgement was upheld by the Appeals Court. In making her decision, Judge Rambo cited:

· Findings that exposure patterns projected by computer models of the releases compared so well with data from the TMI dosimeters (TLDs) available during the accident that the dosimeters probably were adequate to measure the releases.

· That the maximum offsite dose was, possibly, 100 millirem (1 mSv), and that projected fatal cancers were less than one.

· The plaintiffs' failure to prove their assertion that one or more unreported hydrogen "blowouts" in the reactor system caused one or more unreported radiation "spikes", producing a narrow yet highly concentrated plume of radioactive gases.

Judge Rambo concluded: "The parties to the instant action have had nearly two decades to muster evidence in support of their respective cases... The paucity of proof alleged in support of Plaintiffs' case is manifest. The court has searched the record for any and all evidence which construed in a light most favourable to Plaintiffs creates a genuine issue of material fact warranting submission of their claims to a jury. This effort has been in vain."

More than a dozen major, independent studies have assessed the radiation releases and possible effects on the people and the environment around TMI since the 1979 accident at TMI-2. The most recent was a 13-year study on 32,000 people. None has found any adverse health effects such as cancers which might be linked to the accident.

The TMI-2 clean-up

The clean-up of the damaged nuclear reactor system at TMI-2 took nearly 12 years and cost approximately $973 million. The clean-up was uniquely challenging technically and radiologically. Plant surfaces had to be decontaminated. Water used and stored during the clean-up had to be processed. And about 100 tonnes of damaged uranium fuel had to be removed from the reactor vessel – all without hazard to clean-up workers or the public.

A clean-up plan was developed and carried out safely and successfully by a team of more than 1000 skilled workers. It began in August 1979, with the first shipments of accident-generated low-level radiological waste to Richland, Washington. During the clean-up's closing phases, in 1991, final measurements were taken of the fuel remaining in inaccessible parts of the reactor vessel. Approximately one percent of the fuel and debris remains in the vessel. Also in 1991, the last remaining water was pumped from the TMI-2 reactor. The clean-up ended in December 1993, when unit 2 received a licence from the NRC to enter post-defuelling monitored storage (PDMS).

Early in the clean-up, unit 2 was completely severed from any connection to TMI unit 1. TMI-2 today is in long-term monitored storage. No further use of the nuclear part of the plant is anticipated. Ventilation and rainwater systems are monitored. Equipment necessary to keep the plant in safe long-term storage is maintained.

Defuelling the TMI-2 reactor vessel was at the heart of the clean-up. The damaged fuel remained underwater throughout the defuelling. In October 1985, after nearly six years of preparations, workers standing on a platform atop the reactor and manipulating long-handled tools began lifting the fuel into canisters that hung beneath the platform. In all, 342 fuel canisters were shipped for long-term storage at the Idaho National Laboratory, a programme that was completed in April 1990. It was put into dry storage in concrete containers.

TMI-2 clean-up operations produced over 10.6 megalitres of accident-generated water that was processed, stored and ultimately evaporated.

In February 1991, the TMI-2 clean-up programme was named by the National Society of Professional Engineers as one of the top engineering achievements in the USA completed during 1990.

In 2010 the generator was sold by FirstEnergy to Progress Energy to upgrade its Shearon Harris nuclear power plant in North Carolina. It was shipped in two parts, the rotor, which weighs 170 tonnes, and the stator, which weighs about 500 tonnes.

The NRC website has a factsheet on Three Mile Island.

Unit 1

From its restart in 1985, TMI-1 operated at very high levels of safety and reliability before being shut down in September 2019. Application of the lessons of the TMI-2 accident were a key factor in the plant's outstanding performance.

In 1997, TMI-1 completed the then longest operating run of any light water reactor in the history of nuclear power worldwide – 616 days and 23 hours of uninterrupted operation. (That run was also the longest at any steam-driven plant in the USA, including plants powered by fossil fuels.) And in October 1998, TMI employees completed three million hours of work without a lost-work day accident.

At the time of the TMI-2 accident, TMI-1 was shut down for refuelling. It was kept shut down during lengthy proceedings by the NRC. During the shutdown, the plant was modified and training and operating procedures were revamped in light of the lessons of TMI-2.

When TMI-1 restarted in October 1985, General Public Utilities pledged that the plant would be operated safely and efficiently and would become a leader in the nuclear power industry.

- The plant's capacity factor for 1987, including almost three months of a five-month refuelling and maintenance outage, was 74.1%, compared to an industry average of 62%. (Capacity factor refers to the amount of electricity generated compared to the plant's maximum capacity.)

- In 1988 a 1.3% (11 MWe) uprate was licensed.
- For 1989, TMI-1's capacity factor was 100.03% and the best of 357 nuclear power units worldwide, according to *Nucleonics Week*.
- In 1990-91, TMI-1 operated 479 consecutive days, the longest operating run at that point in the history of US commercial nuclear power. It was named by the NRC as one of the four safest plants in the country during this period.
- By the end of 1994, TMI-1 was one of the first two units in the history of US commercial nuclear power to achieve a three-year average capacity factor of over 90% (TMI-1 had 94.3%).
- In October 1998, TMI workers completed two full years without a lost workday injury.
- Following its restart, TMI-1 earned consistently high ratings in the NRC's Systematic Assessment of Licensee Performance (SALP) programme.

In 1999, TMI-1 was purchased by AmerGen, a joint venture between British Energy and PECO Energy. In 2003 the BE share was sold so that the plant became wholly-owned by Exelon, PECO's successor.

In 2009, the TMI-1 operating licence was renewed, extending its operating lifetime by 20 years to 2034. Immediately following this, both steam generators were replaced as TMI's "largest capital project to date".

In 2017 Exelon announced it would shut down TMI-1 unless it received support from the state. The reactor was eventually shut down in September 2019.

Training improvements

Training reforms are among the most significant outcomes of the TMI-2 accident. Training became centred on protecting a plant's cooling capacity, whatever the triggering problem might be. At

TMI-2, the operators turned to a book of procedures to pick those that seemed to fit the event. Now operators are taken through a set of 'yes-no' questions to ensure, *first*, that the reactor's fuel core remains covered. *Then* they determine the specific malfunction. This is known as a 'symptom-based' approach for responding to plant events. Underlying it is a style of training that gives operators a foundation for understanding both theoretical and practical aspects of plant operations.

The TMI-2 accident also led to the establishment of the Atlanta-based Institute of Nuclear Power Operations (INPO) and its National Academy for Nuclear Training. These two industry organizations have been effective in promoting excellence in the operation of nuclear plants and accrediting their training programmes. INPO was formed in 1979. The National Academy for Nuclear Training was established under INPO's auspices in 1985. TMI's operator training programme passed three INPO accreditation reviews since then.

Communications and teamwork, emphasizing effective interaction among crew members, became part of TMI's training curriculum. Close to half of the operators' training was in a full-scale electronic simulator of the TMI control room. The $18 million simulator permitted operators to learn and be tested on all kinds of accident scenarios.

Increased safety & reliability

Disciplines in training, operations and event reporting that grew from the lessons of the TMI-2 accident have made the nuclear power industry demonstrably safer and more reliable. Those trends have been both promoted and tracked by INPO. To remain in good standing, a nuclear plant must meet the high standards set by INPO as well as the strict regulation of the US NRC.

A key indicator is the graph of significant plant events, based on data compiled by the NRC. The number of significant events decreased from 2.38 per reactor unit in 1985 to 0.10 at the end of 1997.

On the reliability front, the median capability factor for nuclear plants – the percentage of maximum energy that a plant is capable of generating – increased from about 65% in 1980 to over

80% in 2000, where it remained.

Other indicators for US plants tracked by INPO and its world counterpart, the World Association of Nuclear Operators (WANO) are the unplanned capability loss factor, unplanned automatic scrams, safety system performance, thermal performance, fuel reliability, chemistry performance, collective radiation exposure, volume of solid radioactive waste and industrial safety accident rate. All are reduced, that is, improved substantially, from 1980.

Summary

What happened:

- After shutting down the fission reaction, the TMI-2 reactor's fuel core became uncovered and more than one-third of the fuel melted.
- Inadequate instrumentation and training programs at the time hampered operators' ability to respond to the accident.
- The accident was accompanied by communications problems that led to conflicting information available to the public, contributing to the public's fears
- A small amount of radiation was released from the plant. The releases were not serious and were not health hazards. This was confirmed by thousands of environmental and other samples and measurements taken during the accident.
- The containment building worked as designed. Despite melting of about one-third of the fuel core, the reactor vessel itself maintained its integrity and contained the damaged fuel.

What did not happen:

- There was no "China Syndrome".
- There were no injuries or detectable health impacts from the accident, beyond the initial stress.

Longer-term impacts:

- Applying the accident's lessons produced important, continuing improvement in the performance of all nuclear power plants.
- The accident fostered better understanding of fuel melting, including improbability of a "China Syndrome" meltdown breaching the reactor vessel and the containment structure.
- Public confidence in nuclear energy, particularly in the USA, declined sharply following the Three Mile Island accident. It was a major cause of the decline in nuclear construction through the 1980s and 1990s.

Notes & references

Sources

GPU Nuclear Corp., 10 briefing papers, 1999
Nuclear Energy Institute, Nuclear Energy Overview 08/05/2000

Related information

[Cooperation in Nuclear Power](#)
[Safety of Nuclear Power Reactors](#)

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