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Three Mile Island Revisited

These days, “TMI” stands for “too much information,” a tweeted warning for friends who divulge uncomfortably personal news. But prior to the age of texting acronyms, TMI conjured images of atomic doom. It stood for Three Mile Island and referred to “the most serious accident in U.S. commercial nuclear power plant operating history.”

That’s how the U.S. Nuclear Regulatory Commission (NRC) remembers the 1979 partial meltdown of a reactor south of Harrisburg, Pennsylvania. At the time, media screeched of potential nuclear nightmare. The public was primed for panic from the release just 12 days earlier of *The China Syndrome*, Hollywood hyperbole about a nuclear meltdown that nearly renders southern California a ruined wasteland.

People feared TMI was a case of life imitating art. The accident “brought about sweeping changes” and “caused the NRC to tighten and heighten its regulatory oversight.” Today, the International Atomic Energy Agency rates TMI as a five out of seven on its radiological event scale, comparable to the Richter scale for earthquakes.

However, NRC admits that the accident’s “small radioactive releases had no detectable health effects on plant workers or the public.” Area residents “received an average radiation dose of only about 1 millirem above the usual background dose,” which people receive daily from natural sources. “To put this into context, exposure from a chest X-ray is about 6 millirem.” Almost 20 years of follow-up with area residents by the Pennsylvania Department of Health produced results published in the March 2003 journal *Environmental Health Perspectives*. Researchers found no link between the accident and disease trends.

What explains the dichotomy? To answer this question, we need to understand how nuclear reactors work and what went wrong at TMI. Then we’ll discuss the undeserved repercussions that still afflict the nuclear industry today.

How a Nuclear Reactor Works

The TMI power plant included two pressurized water reactors (PWR), and the 1979 meltdown happened in Unit 2. The graphic on the next page provides a simplified visual of its construct.

Reactors split atoms — a process called nuclear fission — within the reactor vessel to generate heat. In a PWR, the heat from the primary loop (pictured in red) is exchanged with water flowing through a



wikimedia/Groupmesa

Three Mile Island: TMI’s Unit 1 continued service until 2019. In this archived picture, its cooling towers released pure water vapor as the towers of Unit 2 stood dormant following a 1979 partial reactor meltdown accident.



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secondary loop (pictured in blue), turning that water into steam. The steam spins a turbine, which generates electricity.

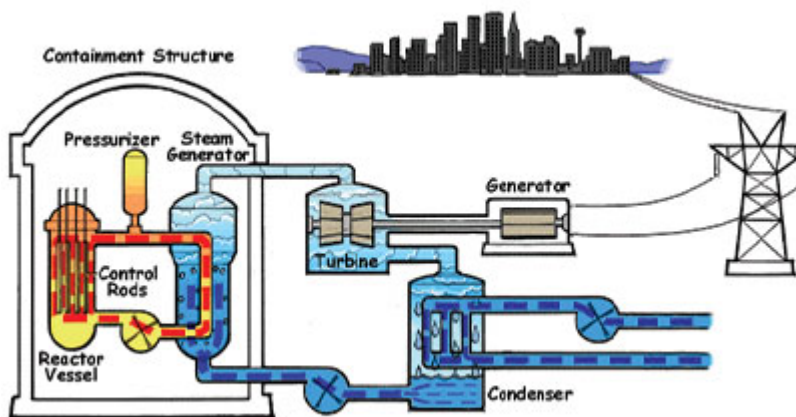
Water in the primary loop acts as a moderator for the nuclear reaction and keeps the fuel rods from overheating and melting. (There is also an emergency core cooling system not pictured here, but we'll discuss that later.)

A PWR maintains water at a very high pressure in the primary loop — around 2,000 pounds per square inch (psig). The high pressure keeps this water from boiling at very high operating temperatures, around 600 degrees Fahrenheit. It's the same concept behind a pressure cooker, but at much higher temperatures.

The pressurizer, located at the highest point in the reactor coolant system, is a vessel that under normal operating conditions contains a water reservoir at its bottom and a steam bubble in its top. Since water is incompressible, the steam bubble controls reactor coolant system pressure. Should that get too high, a pilot-operated relief valve (PORV) at the top of the pressurizer automatically opens, directing steam to a reactor coolant drain tank. Once the pressure drops back within an acceptable range, the PORV automatically closes.

Meanwhile, in the secondary loop, main feedwater pumps provide low pressure water from the condenser to the steam generators.

There are two other terms needed in a discussion of what happened at TMI. First is a *loss-of-coolant accident*, which is any condition in which the coolant system's boundary is compromised so that reactor coolant is lost. In plain terms, it's a leak. Second, is *reactor scram*, a fast insertion of control rods into the reactor core to stop all chain reactions almost instantaneously.



Pressurized water reactor: The primary loop (red) of a PWR keeps water under high pressure to prevent boiling. It heats low-pressure water in the secondary loop (blue) without transmitting radioactivity in the process.

What Went Wrong?

Numerous factors contributed to the meltdown at TMI on March 28, 1979. Paramount among them were a failure of the pressurizer PORV and a couple of poorly maintained plant conditions.



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TMI is the subject of many studies and reports, but most are not written for the public. After all, nuclear power plant operation and safety are complex subjects. The discussion below is an attempt to provide a reader-friendly explanation with information gleaned from various government reports in the months following the accident, a 2004 book about TMI by nuclear-age historian J. Samuel Walker, a 2011 textbook on lessons in accident management from TMI written by former NRC commissioner Robert E. Henry, and an article on TMI by former American Nuclear Society President William E. Burchill, published by *Nuclear News* in 2019.

Evolving Accident Sequence

The accident began at 4:00 a.m. in the secondary loop, when a clogged feedwater deionization tank reduced flow to the main feedwater pumps, causing the pumps to shut down and stopping the flow of water from the condenser to the steam generators. That loss of cooling water caused the plant safety system to automatically trip the steam turbine off-line.

With nothing to cool it, the primary loop's pressure and temperature rapidly began to rise. The plant's redundant reactor protection system commands caused an instant reactor scram.

The situation also caused a rise in the pressurizer water level. Hence, the PORV opened. That, in conjunction with the reactor scram, caused a rapid pressure drop. Once the pressure dipped to 1,600 psig, the emergency core cooling system's high-pressure safety injection pumps automatically actuated, adding water to the primary loop to increase the system pressure and prevent boiling.

So far, so good. Everything happened as it should have for recovery from a loss of feedwater to the steam generators. Even the emergency feedwater system automatically activated in response to the loss of the main feedwater pumps.

However, a human error prevented the emergency feedwater from reaching the steam generators. Someone had mistakenly left the emergency feedwater isolation valves closed following recent system maintenance. Why did none of the operators notice? Likely because many components on control room panels were "tagged out" for maintenance. Those dangling tags obscured many indicator warning lights. Thus, about two minutes after the main feedwater pumps tripped, the steam generators boiled dry.

Loss of Coolant

Everything described so far happened within the first three minutes of the accident. But there was another combination of mechanical and human error that lasted much longer and sealed TMI's fate.

It involved the PORV atop the pressurizer. After the main feedwater pumps tripped, the PORV opened to release pressure building in the reactor coolant system. However, it failed to automatically close once pressure dropped below the relief setpoint, and it remained open for nearly two and a half hours.

No one realized the problem. A control room indicator showed that a signal had been sent to close the valve, but nothing alerted operators to the fact that it was stuck open. The pressurizer steam bubble was expelled and reactor coolant continued to flow through the valve, creating a loss-of-coolant accident.

It was a malfunction and error that would not have happened had communication failures not plagued the industry. The *Report of the President's Commission on the Accident at Three Mile Island*, published



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October 30, 1979, complained that PORVs identical to the one that malfunctioned at TMI had failed in other locations. Among these, events at the NOK-1 plant in Switzerland in 1974, the Oconee-3 plant in South Carolina in 1975, and the Davis-Besse-1 plant in Ohio in 1977 mimicked the situation at TMI. The difference was that operators quickly recognized and solved the problem. Had their experiences been broadcast, the information could have significantly mitigated the duration and outcome of TMI.

Yet both the reactor vendor and the NRC failed to warn PWR owners/operators. Their rationale was the existence of a PORV discharge temperature monitor that would indicate failure of the valve to reclose and an isolation valve in the PORV discharge piping that could be remotely closed to terminate a loss of coolant. However, the likelihood of PORV failure should have been reason enough for the NRC to issue a Preliminary Notification Report.

Also ignored was a 1978 Tennessee Valley Authority (TVA) engineer's analysis of loss-of-coolant accidents in plants like TMI manufactured by the Babcock & Wilcox Company. The study concluded that pressurizer water level was not a reliable indicator of reactor coolant system conditions and that operators should not rely on it to dictate their actions. The TVA, the NRC, and Babcock & Wilcox all share responsibility for downplaying (or ignoring) the significance of an analysis that would likely have helped avoid the TMI reactor core melt. In the next section, we'll describe how this played a part.

A Perfect Storm

With both the main and emergency feedwater systems disabled, and with the PORV stuck open, the reactor coolant system was hemorrhaging water and heating rapidly. Operators were in uncharted territory. The accident began to involve aspects that were not anticipated in the plant's original safety analysis. In industry terms, it was "beyond-design basis."

After about five and a half minutes, remaining water in the reactor core began boiling. The decreased heat removal from the reactor fuel resulted in overheating of the fuel and rupturing of the fuel rod cladding. The damaged cladding reacted with steam to produce combustible hydrogen gas, and the gas leaked into the containment building through the open PORV.

Meanwhile, the loss of the steam bubble in the pressurizer caused operators to believe that the core was covered with water and to throttle the emergency core cooling system's high-pressure injection pumps to prevent over-pressurizing the reactor coolant system. Unbeknownst to them, however, the core was not flooded. The persistently high pressurizer water level was due to an obscure thermal-hydraulic phenomenon whereby the upward flow of a gas (steam) prevents the downward flow of a liquid (water). It's called "countercurrent flooding"; steam rising from the reactor core through the pressurizer inlet piping literally suspended water in the pressurizer. (This was part of the TVA engineer's ignored warning discussed earlier.)

Eight minutes after the accident began, staff discovered that the secondary loop's emergency feedwater isolation valves were closed. They opened them, restoring cooling capability of the steam generators.

However, they would not realize the PORV problem until more than two hours later. False containment-building radiation monitor readings led operators to believe that a loss-of-coolant accident wasn't happening. About an hour and a half later, someone discovered the monitor's charcoal filter was waterlogged, rendering the monitor non-functional. That's when staff started looking for a loss-of-coolant source and found it by shutting the PORV isolation valve that functioned as a safeguard in case of PORV



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malfunction.

There were other unexpected conditions that led to operator actions that further aggravated the accident response, including misinterpretation of many instrumentation readings resulting from reactor coolant system conditions that were not fully understood by plant operators or management.

As a result, the reactor coolant system lost roughly two-thirds of its coolant into the reactor containment building. The temperature in the reactor core rose to around 4,000 degrees Fahrenheit. After about four hours, the upper part of the core melted and slumped to the bottom of the reactor pressure vessel. Despite fuel melting, the debris “froze” quickly upon contact with the bottom of the vessel, so no damage was incurred by the vessel, as illustrated in the graphic. Operators restored primary system coolant flow after 16 hours, essentially terminating the accident.

Radiological Consequences

Radiological consequences of the accident to humans and the environment were insignificant because the ultimate fission product retention barrier, the reactor containment building, remained intact. Not only did it retain fission products released from the damaged reactor fuel, but it also withstood a hydrogen burn that occurred around 10 hours after accident initiation. The burn produced a pressure spike of approximately 28 psig in the containment building, which was only about one-half of its maximum design pressure.

The release of volatile fission products was three to four orders of magnitude smaller than limits set by the Atomic Energy Commission when it originally licensed TMI in 1962.

The only radiation released outside of the containment building was from radioactive krypton and xenon gases. It happened during a transfer of the gases to a decay tank and was intentional, not accidental. These releases had the *potential* to expose area residents to the one-millirem background dose recorded by the NRC, or about the average daily dose from natural background radiation in that part of Pennsylvania.

The Aftermath

Positive post-TMI changes within the industry involved enhanced monitoring and maintenance, control room redesign, upgraded operator training, better risk assessments, and improved industry communication, especially for abnormal event reporting. However, the TMI accident severely damaged public perception of nuclear power.

“The truth is that one of the most covered stories of the 1970s was so poorly communicated to the public that today, history remembers Three Mile Island as an unmitigated disaster, and not what it actually was: an inevitable series of human errors that resulted in a harmless failure.” So says science journalist Kyle Hill in an educational video on his YouTube channel. He calls TMI one of the “worst PR disasters of all time.”

For example, two days after the accident, Pennsylvania’s governor “encouraged” pregnant women and preschool children within five miles of the plant to leave the area “until further notice,” while the state emergency management agency drew up evacuation plans for a 20-mile radius affecting six counties and 650,000 people. No evacuation was ever ordered, but panic ensued regardless. Schools closed, and many residents fled.



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The report of the President’s Commission would later reveal that NRC had erred in its calculations of risk related to the accident but “made no announcement,” leaving the “good news unshared with the public.”



Nuclear casualty: Physicist Edward Teller suffered a heart attack shortly after the TMI accident. He blamed it on stress he endured while defending nuclear power against propaganda from hostile leftists.

Even President Jimmy Carter, who arrived April 1 to assess the site, and whose opinion mattered due to his nuclear experience in the U.S. Navy, “told his staff after visiting the plant ... that he didn’t think it was even a disaster. He thought it was minor,” relates Hill. Yet Carter reportedly “refused to tell the public this at the time, for fear of offending anti-nuclear Democrats in the U.S. House and Senate.”

Stress, not radiation, injured people. “The conspiracy theories and anecdotal evidence and anti-nuclear panic that Three Mile Island generated, and still generates, have likely done more to harm public health through stress than any radiation released in 1979,” speculates Hill. Indeed, four months after the accident, physicist Edward Teller, known as the “father of the hydrogen bomb,” wrote a two-page spread in *The Wall Street Journal* in defense of nuclear power’s safety and reliability. “I was the only victim of Three-Mile Island,” ran the headline, and Teller revealed that under the strain of refuting propaganda frightening people “away from nuclear power,” the 71-year-old suffered a heart attack.

Lessons Not Learned

Teller was wrong only in that he was certainly not the sole victim. Others suffered debilitating stress, and everyone who pays a utility bill today suffers from damage to the industry by anti-nuclear forces and hostile media.

“After TMI, the number of reactors under construction in the U.S. started to decline for the first time since 1963,” Hill says. “Fifty-one nuclear reactors were canceled between 1980 and 1984. No new nuclear power plant would be authorized for construction in the United States until 2012. What took their place were coal-fired power plants which would soon contribute to more preventable deaths by pollution than all nuclear accidents ever, combined.”

TMI also revealed some facts still ignored and still not adequately communicated to the public, even though the experiences at Chernobyl in 1986 and Fukushima in 2011 underscore their validity. These have to do with the modest public consequences of reactor core meltdown accidents.



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There are two reasons for those modest results. The first is that Western nuclear power plants, unlike Chernobyl, are designed with reactor containment structures that retain radioactive fission products from damaged nuclear fuel. The second, as revealed in the TMI and Fukushima accidents, is that the more volatile fission products plate out on containment structure surfaces and therefore become immobilized.

Most importantly, there is no observed incidence of radiation-induced disease from either TMI or Fukushima. Predictions of increased cancer mortality were just that — predictions — and history has proven them to be grossly untrue. They are mistaken because they are based on a radiation dose-response model known as linear no-threshold (LNT), which erroneously holds that all radiation exposures are harmful, no matter how small.

Even Chernobyl proves the fallacy of LNT. Except for doses received by first responders, public exposure did not result in significant adverse health consequences. In fact, many elderly people returned to their homes in the Chernobyl Exclusion Zone, in violation of government orders, and experienced no adverse health effects. Furthermore, the increased number of thyroid cancers detected in the population of the contaminated area shortly following the accident was not in agreement with thyroid cancer latency of eight to 10 years after irradiation. Increased post-Chernobyl testing accounts for an increase in thyroid cancer diagnosis in the 1980s.

Until these facts are widely understood, irrational fear holds sway and prevents the expansion of nuclear power. Fear is an underappreciated emotional driver in today's America, and the fearmongers are using it to their advantage. The Covid debacle showed that many Americans are apparently content to live their lives in fear. It is hoped that, regarding nuclear power, rising concerns about energy security and costs will help overcome unfounded phobias and misconceptions.



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