The Three Mile Island Disaster's Legacy in Nuclear Energy Safety

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by

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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In 1979, seven years before the Chernobyl incident, the Unit 2 reactor at the Three Mile Island nuclear power plant in Londonderry Township, Pennsylvania, experienced a partial meltdown. In response to the accident, President Jimmy Carter issued an executive order that established a commission of 12 analysts who described the incident as "the worst accident in the history of commercial nuclear power generation" (Kemeny et al., 1979). The disaster was the impetus for a reevaluation of safety in nuclear power plants. The president's commission, the Nuclear Regulatory Commission (NRC), and antinuclear advocacies competed to influence the reevaluation.

Each of these social groups emphasized a unique aspect of safety in their response to the TMI disaster. The president's commission recommended "a total restructuring of the NRC," and concluding that "the fundamental problems are people-related problems and not equipment problems" (Kemeny et al., 1979). The Nuclear Regulatory Commission (NRC), in turn, extensively revised regulations, stressing the training of plant personnel. To antinuclear advocacies, however, the fault lay in nuclear power itself, which they regarded as inherently unsafe.

Review of Research

Researchers have considered how risk is assessed and how safety is promoted in response. Perrow (1984) argues that systems which are, in his words, "complex" and "tightly coupled" lead to unforeseeable, but inevitable failures. Complex interactions are not anticipated by designers or are not discernable to operators. Tightly coupled interactions "happen very fast and can't be turned off, … cannot be isolated from other parts, … or there is no other way to keep production going safely.” Perrow contends that organizational changes following the TMI incident were insufficient to prevent another disaster.

Oakes and Bor (2010) investigated the effects of social interactions on safety and the fear of flying on airplanes. They reported that “belligerent or aggressive behavior among some passengers may also be fueled by anxiety” and that anxious flyers exhibit an “increased tendency to use medication and alcohol when flying.” Both behaviors have the potential to lead to a failure to follow safety procedures and add complexity to the passenger airplane system, which results from the anxiety of passengers. Also, they note that the most “obvious behavioural response to a fear of flying is avoidance” Bromet (2011) found that TMI and other nuclear core meltdown events could result in severe psychological consequences that are in some cases more severe than the physiological effects resulting from radiation exposure. Bromet concludes for persons who believe that they are at risk from a nuclear incident “a range of symptoms was elevated up to six years after the accident, including somatic complaints, generalized anxiety, post-traumatic stress, and depression.” A significant contributor to these symptoms was the “confusing and contradictory information about what exactly was occurring at the reactor and whether their health was at risk.”

The management of risks will reference The National Institute for Occupational Safety and Health’s (NIOSH) Hierarchy of Controls (2023). The Hierarchy of Controls divides methods of handling risk into five groups in order of general effectiveness. In order, these are “Elimination, Substitution, Engineering controls, Administrative controls, and Personal protective equipment (PPE).” Those of most interest to this research are: elimination or “removing the hazard,” substitution or “replacing the hazard,” and administrative controls or “changing the way people work.”

The President’s Commission

The report by the President’s commission analyzed the technical aspects of the event, its causes, “the role of managing utility,” the “emergency preparedness and response” of the NRC, and how “right to information concerning the events at TMI was served” (Kemeny et al., 1979). Discounting technical deficiencies at TMI, the commission concluded that human error was the more important cause. Nevertheless, the commission found that “the pilot-operated relief valve (PORV) at the top of the pressurizer ... failed to close when pressure decreased,” permitting coolant loss (Kemeny et al., 1979). However, as Perrow illustrates, the failure of the PORV valve was not the first point of failure. Indeed, it was one of the final safety systems to fail. First, a small leak in the secondary coolant system caused it to stop removing heat from the primary coolant system, which caused the PORV valve to open and release heat for safety. Perrow identifies four equipment failures that were part of a complex and tightly interacting control system.

The Kemeny report goes on to say, “Some of the key TMI-2 operating and emergency procedures in use on March 28 were inadequate” and concluded that “the equipment was sufficiently good that, except for human failures, the major accident at Three Mile Island would have been a minor incident” (Kemeny et al., 1979). However, the problems that contributed to TMI cannot be attributed to operator error when one considers the complexity and lack of clear information during the event. While it is true that operators could have prevented the incident, the equipment failures were difficult for operators to discern. For example, the PORV position indicator showed that the valve was closed even though it was stuck open and pressure indicators showed rising water level in the pressurizer but falling pressure in the reactor vessel. These indicators should have moved in concert. In response to the rising pressure in the pressurizer

> the operators… were concerned that the plant was "going solid," that is, filled with water. Therefore, they cut back HPI from 1,000 gallons per minute to less than 100 gallons per minute… This led to much of the core being uncovered for extended periods on March 28 and resulted in severe damage to the core (Kemeny et al., 1979).

Cutting back the high-pressure injection (HPI) system led directly to the meltdown that followed, but if the core vessel had come under sufficient pressure and thermal fluctuations from the HPI system as the operators at TMI believed, the meltdown may have breached the pressure vessel. According to the report, “no amount of technical "fixes" will cure this underlying problem” (Kemeny et al., 1979). They are correct in identifying that additional safety systems are unlikely to prevent future incidents. After all, the PORV valve was itself intended as a safety system to prevent the buildup of heat and pressure in the reaction vessel. However, as one supervisor at TMI stated, “each time [the operators] made a decision it was based on something we knew about” (Perrow, 1984). Considering that “specific exposure, whether real or perceived is highly dreaded and pernicious because it is conflated with nuclear weapons,” it can be expected that operators may act in an irrational manner, but this is not the case for the operators at TMI (Bromet, 2011).

Davis-Besse Incident

Though equipment failure was not considered the main cause of failure, the report criticizes the lack of action by the NRC and the valve’s manufacturer, B&W, to fix the valve’s deficiencies. Indeed, the pressure valve's failure to close was reported in a nearly identical incident two years earlier when

> an incident occurred at the Davis-Besse plant, also equipped with a B&W reactor. During that incident, a PORV stuck open and pressurizer level increased, while pressure fell (Kemeny et al., 1979).

This incident was largely ignored since "the Davis-Besse plant had been operating at only 9 percent power," and no major meltdown resulted from the accident (Kemeny et al., 1979). Because this incident did not result in a major meltdown, "no information calling attention to the correct operator actions was provided to utilities prior to the TMI accident," despite investigations conducted by both B&W and the NRC (Kemeny et al., 1979). Despite being a known point of failure, wholly insufficient preventative action by both the NRC and B&W allowed the same breakdown to occur at TMI while the plant was at full power. The lack of notification may also have resulted from the belief that the HPI system, which is designed to replace primary coolant in the event of depressurization, would be sufficient to prevent a meltdown. However, the NRC and B&W failed to consider how the operator might react in the face of contradictory information from the pressurizer level and the core vessel pressure. Since running the HPI system when the PORV valve is closed and the core vessel is under pressure may result in the rupture of the core vessel, the correct procedure that an operator should follow is unclear. Furthermore, the prospect of core vessel rupture and the resulting radiation exposure may cause anxiety for the operators and lead them to avoidance or irrational behaviors (Oakes and Bor, 2010).

However, the Davis-Besse incident was not met with a complete lack of action. The commission identifies "an internal B&W memorandum written more than a year before the TMI accident that if the Davis-Besse event had occurred in a reactor operating at full power 'it is quite possible, perhaps probable, that core uncovery and possible fuel damage would have occurred'" (Kemeny et al., 1979). This memorandum was written by a regional inspector named James Cresswell. Forty-five years later, I had the opportunity to hear a presentation from Mr. Cresswell at a splinter company from B&W, BWXT. Cresswell raised his concerns about the incident's safety implications through proper channels in vain and eventually broke the chain of command to send a memo to upper management in 1978 (Bushbaum, 2011). Unfortunately, this was met with inaction from B&W and the NRC as the commission notes again "no notification was given to utilities prior to the accident" (Kemeny et al., 1979). Because of the NRC's failure to act, the President's commission concluded that "fundamental changes will be necessary in the organization, procedures, and practices -- and above all -- in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry" (Kemeny et al., 1979).

NRC Reform

Ten years after TMI, the NRC published a review of their progress in achieving the reforms recommended by the president's commission. The most relevant of these reforms are the NRC's changes to the training of personnel, emergency preparedness, and the dissemination of information to the public. Due to the emphasis that the President's commission placed on operator error, the licensing of operators and technicians experienced major changes. Training programs for operators were established that were required to "implement what is referred to as performance-based training" (NRC, 1989). These new training programs began with an analysis of the skills required for a particular job, built the training around those skills, and then evaluated a trainee's mastery of these skills. They would also "revise the training based on the performance of trained personnel in the job setting" (NRC, 1989). These programs were accredited by the Institute of Nuclear Power Operations (INPO) and the accreditation process was overseen by the NRC (NRC, 1989). All training programs emphasized the use of control room simulators to train and test proficiency in "the diagnosis of and recovery from possible plant transients" (NRC, 1989).

All these changes were made in response to the commission's emphasis on operator proficiency. However, the changes to operator training fall under what the NIOSH classifies as "administrative controls," which are classified as the second least effective control mechanism. Nuclear power stations also often have operating requirements that are unique, and differences in scale, reactor type, and manufacturers can change a plant's operating procedure. Also, nuclear technology is not stagnant, which will cause continual changes to how some nuclear power stations must be operated. Finally, in a system with as much interactive complexity as a nuclear power station, it can be reasonably expected that an event will eventually occur that operators have not been trained to handle. Perrow (1984) writes, "without experience, we cannot be sure of the potential for damage inherent in the system's characteristics."

For this reason, better training alone is insufficient, but there are key features of the NRC's training reforms that help it handle the complexity of nuclear power plants. All licensed utilities are required to have "simulation facility appropriate to conduct operator licensing tests," which occur annually. These simulators are designed to test "operator currency and competency for the facility for which they hold an NRC license" (NRC, 1989). They accomplish this by requiring that "each simulator must be able to replicate events that have happened at that facility" (NRC, 1989). Though this does not contradict Perrow's warning, it can still help prevent catastrophic system failure because of the longstanding "defense in depth" safety principles applied in the nuclear industry. Defense in depth is a widespread safety principle that the International Nuclear Safety Advisory Group (INSAG) defines as "layers of overlapping provisions, so that if a failure should occur it would be compensated for or corrected without causing harm to individuals or the public at large" (INSAG, 1996). For example, in the TMI disaster, though the reactor experienced a partial meltdown, the reactor vessel was not breached, but if it had been, the concrete containment building would likely have minimized the public's radiation exposure. Failures in nuclear power systems are common, but it is much rarer for them to fail catastrophically, which gives the NRC and INPO the opportunity to adjust accreditation requirements to mitigate these modes before a series of system failures occur that produce a major incident. In addition, a new "Safety Parameter Display System (SPDS) [was] provided for critical plant parameters to enhance operators' understanding of the plant's safety status" (NRC, 1989). The indicators on the SPDS are centrally located and contain more direct measures of relevant safety information than those that caused confusion during the TMI disaster.

Dissemination of Information

Another important aspect of the NRC's reforms is their commitments to clear dissemination of information to utilities and the public. The President's commission notes that during the TMI incident "NRC officials contributed to the raising of anxiety in the period from Friday to Sunday," and "the mental stress to which those living within the vicinity of Three Mile Island were subjected was quite severe" (Kemeny et al., 1979). The psychological effects of perceived or real radiation exposure are non-trivial. Bromet, Parkinson and Dunn (1990) found that in the wake of the Fukashima nuclear disaster, "the rate of clinical depression and anxiety among mothers of young children living near the plant was double that of a comparison group in the year after the accident" (Bromet et al, 1990). In response to the commission's requirements, the NRC established a Joint Public Information Center (JPIC) where "where Federal State and utility officials operate so that where the facts warrant a coordinated view of the situation can be presented" (NRC, 1989). Rather than having multiple perspectives on the same information, utilities, the NRC, and the state are responsible for separate topics, so that a single clear message is presented to the public.

In addition, licensed utilities are required to work "with State and local government organizations for announcements to be made over the Emergency Broadcast System… in order to disseminate appropriate information to the public" (NRC, 1989). The NRC's efforts to reduce the risk of nuclear energy and prepare for the next catastrophic failure met the requirements set forth by the President's commission. However, the TMI disaster also caused "growing distrust of authorities amidst the perplexing, ambiguous, and inconsistent reports," which led public advocacies to question if the dangers inherent to nuclear fission reactors are should be tolerated.

Public Protest

In contrast to the President's commission, the NRC, and the nuclear power industry, public advocacies criticized nuclear energy as a whole and the lack of public transparency. Shortly after the TMI incident, an activist group called Musicians United for Safe Energy organized a concert in New York to protest nuclear power and raise funding for antinuclear groups (MUSE, 1979). The "No Nukes" concert was attended by around two hundred thousand people and featured fourteen different performers (MUSE, 1979). Ralph Nader, a speaker at the concert, told the crowd, "stopping atomic energy is practicing patriotism; stopping atomic energy is fighting cancer; stopping atomic energy is fighting inflation" (Herman, 1979) Songs such as "Power" by The Doobie Brothers featured lyrics that provoked fear of nuclear power saying, "won't you take all your atomic poison power away" and "I know that lives are at stake." The advocates at the rally also expressed public discontent because of the lack of clear communication in the wake of the TMI incident. At the rally, a performer, Jackson Browne, said, "I have a right to know why my life is being endangered by someone's profit margin" (Dodd, 2011).

MUSE and other advocacies were an important voice that helped to lend importance to the TMI investigation. The rally coordinator, Donald Ross also told the New York Times that "antinuclear leaders had delivered to President Carter a proposal for a rapid phase-out of all operating reactors in the United States" (Herman, 1979). Though no plan to rapidly phase-out nuclear energy was ever enacted, the Kemeny report stated that "after many years of operation of nuclear power plants, with no evidence that any member of the general public has been hurt, the belief that nuclear power plants are sufficiently safe grew into a conviction," and that this conviction must be discarded for nuclear energy to be safe (Kemeny et al., 1979). Without the strong response from the public, the TMI incident my not have caused such widespread reform in the nuclear industry as "the radiation was contained and the actual release [had] a negligible effect on the physical health of individuals" (Kemeny et al., 1979).

Antinuclear groups advocated for the elimination of nuclear energy or substitution with renewable energy sources, which the NIOSH hierarchy of controls lists as the two most effective control methods. Perrow (1984) predicted that "one or more [accidents] will occur in the next decade and beach containment," and the Chernobyl disaster seven years after TMI, whose consequences eclipsed TMI's, proved him right. Meanwhile, most of the reactors in the United

States are pressurized water reactors, the same type of reactor that failed in TMI. However, in the forty-five years since TMI, the United States has not experienced an accident as severe as TMI. Indeed, modern studies have shown that nuclear energy has resulted in a comparable number of deaths per terawatt-hour as renewable sources of energy and far less than fossil fuels (Savacool & Monyei, 2021). Though failure in a nuclear plant can be catastrophic, regulators have determined that it is safe enough to persist without fundamental changes to reactor design.

Conclusion

The recommendations made in the Kemeny report and the reforms made by the NRC in response were effective in reducing the risk of fission reactors. Though the Kemeny report emphasized "human error" as a leading cause for the accident at TMI, their recommendations did not focus on reducing the responsibilities of operators or adding more automatic safety measures. Instead, reforms expanded the importance of technicians and operators while reducing the complexity of safety systems where possible. It is likely that decommissioning nuclear reactors or developing a safer types of reactors may be more effective, but the NRC's reforms effectively balanced the interests of the nuclear power industry with public safety. However, Cresswell, who recently retired from the NRC, brought forth his concerns over ab experimental small modular reactor that the NRC was in the process of licensing. He explained that the NRC was falling into the mindset of "checking boxes" during licensing rather than reevaluating their practices for the new reactor. As nuclear technology evolves, if the nuclear power industry stops considering nuclear technology as inherently dangerous, we will likely experience another incident on the scale of TMI in the near future.

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