

The ordeal at Three Mile Island

A combination of design deficiency, mechanical failure, and human error contributed to the ill-controlled accident that was touched off at about 4 a.m. on Wednesday, March 28, at Unit 2 of the Three Mile Island nuclear power station of Metropolitan Edison Company, a member company of General Public Utilities (GPU). The initial event at the unit, located near Harrisburg, Pa., has been characterized as a loss-of-normal-feedwater turbine trip—with complications. As Norman Rasmussen of M.I.T. explained the following Sunday on ABC's television program "Issues and

Answers," the event could not be considered, in the parlance of reactor safety studies, a "major event" ("an event of major consequences" to the public health and safety, he quickly went on to clarify). The TMI-2 "event," however, certainly promises to have major consequences for the utilization of nuclear power in America and elsewhere—this in spite of the fact that the accident was contained and the amounts and forms of radioactivity that did escape from the plant, appeared, by most accounts, to have been of no major consequence.



If not calamitous, however, the accident was indeed most serious. Considerable fuel failure occurred, fission products were released into and out of the containment and into the atmosphere, and a tremendous loss, in terms of failed and suspect fuel, the staggering costs of eventual cleanup, and lost confidence, has been visited upon Metropolitan Edison—not to speak of the entire nuclear effort.

Buildup to a crisis

The TMI-2 incident occurred one year to the day after it had first achieved criticality. It was operating at 98 percent of full power. In a matter of minutes during the early morning hours of March 28, it was off line, the secondary system was out of service, the pressurizer relief valve was stuck open, and primary system water was spilling into the containment structure, subsequently to be pumped out to the reactor auxiliary building, from which radioactive gases would escape to the atmosphere (see “How It Happened,” below).

In spite of the severity of the situation, it was not until almost 7 a.m. that a site emergency was declared. High activity readings in the reactor building were then noted, prompting the call for a general emergency at about 7:30 a.m. The utility also notified the Nuclear Regulatory Commission’s Region I office outside Philadelphia, and Civil Defense in nearby Harrisburg. State and federal officials alike have taken Metro Ed to task for not issuing notification until nearly four hours after the initiation of the accident.

The NRC dispatched a team to the site and began taking radiation readings—as did the Pennsylvania Department of Environmental Resources. Ventilation in the auxiliary build-

A President treads lightly

In his energy speech on April 5—one week after the Three Mile Island accident—President Carter had little to say about the future role of nuclear power in achieving the stated goal of energy sufficiency. Just as he wore protective plastic shoe covers in his post-accident visit to TMI-2, the President trod lightly over the subject, saying at the outset of his speech that the accident “demonstrated dramatically that we have *other* energy problems” and adding later that he had established an independent Presidential commission of experts “to investigate the causes of the accident and to make recommendations on how we can improve the safety of nuclear power plants. You deserve a full accounting and you will get it.”

Among the avenues toward energy independence, he mentioned solar energy, shale oil, advanced coal technology, improved automobile efficiency, improved mass transit systems, and even wood-burning stoves. He made no mention, however, of nuclear power, whether fission or fusion.

ing continued, radioactivity in the containment remained high, and the “bubble” in the reactor presented a major obstacle to achievement of cold shutdown. By the end of Wednesday, it was generally agreed that this was the most severe commercial nuclear accident to date, and that the worst may not have been over.

As the gravity of the situation became clear, the NRC beefed up its presence at the site. Harold Denton, director

How it happened

The actual sequence of events beginning early in the morning of March 28 is believed to have gone as follows:

- At about 4 a.m., the main feedwater system of Three Mile Island-2 malfunctioned, apparently as a result of failure either of the demineralizer or of the air supply to an air-operated valve.
- With the main feedwater supply system out of operation, the auxiliary feedwater system was to have started automatically. It did not, however, because a number of manual valves in the auxiliary system had inadvertently been left closed after a test of the system in the days prior to the accident.
- Without feedwater supply, the steam generators dried out, resulting in a rise in the primary coolant temperature and pressure. The turbine generator tripped. The over-pressurization generated a signal that scrambled the reactor.
- Within seconds, primary loop pressure rose to 1.625×10^7 Pascal (2355 psi), triggering a relief valve at the top of the pressurizer. The primary coolant, thus relieved, was piped to a quench tank, located within the containment. The relief valve failed in the open position, providing a continuous release of coolant from the system. This failure and the failure in the main feedwater system (both of a mechanical nature), and the malfunction of the auxiliary feedwater system were the main initiators of the incident.

- The emergency core-cooling system started automatically at two minutes into the accident sequence, and began to raise the coolant level. Within a few minutes, the level indicator for the pressurizer is reported to have started giving erroneously high readings and in fact went off scale on the high side—while actually the opposite condition should have been indicated. An operator manually overrode first one high-pressure injection pump (ECCS) and, a few minutes later, the other. It is believed that this was done to prevent the pressurizer from becoming “solid” (filled entirely with water); if the pressurizer were filled, pressure control would be lost.
- Within two minutes of the first ECCS shutoff, it has been reported, primary coolant was flashing to steam in the reactor.
- Also after the first ECCS shutoff, containment basement sump pumps began to operate automatically (containment isolation at TMI-2 is not automatic with ECCS initiation, but only after pressure within the containment reaches four psig). Several minutes later the feedwater flow was restored, increasing pressure in the steam generators.
- With flow through the pressurizer relief valve unchecked, the quench tank continued to fill, and some fifteen minutes into the accident sequence its rupture disc blew open, releasing ultimately upwards of 40 000 litres of primary coolant onto the containment floor. From here the water was pumped into a storage tank in the auxiliary building, where water spilled again after the tank, already partly filled, exceeded capacity. Radioactive isotopes of krypton, iodine, and xenon began to escape to the environment

of the Office of Nuclear Reactor Regulation, led a contingent from NRC headquarters and became the agency's spokesman at the frequent news conferences held during the next few days. Help was also brought in from other NRC regional offices, and from virtually every national laboratory.

Also sent in were utility and industry teams (including, of course, the B&W personnel), teams from state and federal agencies, and scientists and engineers from outside the United States. Other teams in Washington, D.C., and elsewhere in the United States worked full-time on the problem.

A huge press contingent also gathered in the towns of Middletown and Goldsboro, very close to the site, and in Harrisburg. The press generally is credited with doing a good job of reporting on the incident in spite of some confusion during the initial stages.

There was often disagreement in the reports from the Metropolitan Edison Company and those of the NRC concerning the status of the plant and the progress in the efforts to cool down the reactor. Some of this was understandable as it was apparently not known at first how serious the problem was and, in some instances, because one source had more recent information than the other. But even when working from similar information, the reports from the company and NRC differed, with the reports from the utility almost always carrying a more optimistic tone than those from the Commission. As the press increasingly noted these differences, and as the situation was becoming acrimonious between the NRC and the utility, the White House ordered on April 1 that all further technical reports on the status of the plant were to come from the Commission.

through the building's ventilation system; vent filters trapped much of the iodine but did not stop the noble gases.

- The primary coolant continued to be released from the primary system through the open pressurizer relief valve, resulting in a decrease in primary pressure. At one hour and fifteen minutes after the initial transient, and at about 1300 psi, two primary coolant pumps on one steam generator loop were manually tripped, apparently to prevent cavitation and resultant damage to the pumps. The other two pumps were tripped, again manually, 25 minutes later. At this point the reactor system was without forced convection and without a heat sink.

- Control of the pressurizer relief system was regained, and the ECCS turned on again. It is believed, however, that coolant level had dropped so low that part of the core had been uncovered resulting in substantial fuel damage. Although temperatures in the core registered quite high, no actual melting is believed to have occurred.

- At the three-hour point it was noted that primary-to-secondary leaks in the 'B' steam generator had occurred, providing a pathway for more radioactive material to the environment from the secondary system. The 'B' steam generator was substantially isolated; the 'A' steam generator remained functional.

- It is postulated that the substantial core damage, combined with high fuel temperatures, resulted in the formation within the reactor vessel of a gas bubble, consisting of hydrogen (from Zircaloy-water reaction) and gaseous fission products. The bubble presented a problem in cooling: If primary system pressure were reduced, the bubble

Radioactivity

By the morning of April 3, the NRC had announced the following cumulative data from environmental monitoring:

- No radioiodine was detected in any of the 130 water samples taken by the NRC, the Department of Energy, and the Commonwealth of Pennsylvania since the accident. From what was calculated as the amount of radioiodine released from the plant by water, the thyroid dose to anyone drinking the water was estimated to be less than 0.2 millirem.

- Eight of the 152 offsite air samples showed radioiodine present, the most activity measured being 2.4×10^{-21} microcuries per millilitre. Thyroid dose to anyone at the site boundary was estimated to be less than 50 mrem over a five-day period. Radioactive inert gases were detected in the sample, taken within a 65-km radius of the plant, but the maximum activity detected was about one-fourth of the permissible concentration established in 10CFR20.

- Milk samples tested by the state did not yield radioiodine, but the federal Food and Drug Administration found results ranging from 14 to 40 picocuries of I-131 per litre in the nine samples it took. Herds are to be placed on stored feed, according to the Department of Health, Education and Welfare, when the I-131 count reaches 12 000 pCi/l. The thyroid dose for anyone drinking milk is estimated to be less than 0.5 mrem per day.

- No radioiodine was detected in any of 147 soil samples taken by the NRC and the DOE, nor in 171 vegetation samples taken within 3 km of the site by the NRC, the DOE, and the state.

Radioiodine in the plant was determined (activity adjusted to decay as of midnight, April 2-3) to be 5.1×10^8 Ci in

would expand and possibly impair the cooling mode (e.g., cause pump cavitation).

- Hydrogen also became a problem in the containment. In the beginning phases of the accident the containment pressure had risen above atmospheric. Later on, hydrogen was detected, which, if allowed to accumulate, had the potential for leading to an explosion.

- By Wednesday evening, cooling of the damaged core was restored by activation of one of the primary coolant pumps on the 'A' loop, using the 'A' steam generator as a heat sink. The degasifying process involved drawing dissolved gas out of the coolant from the cold leg of the primary system and spraying it through the pressurizer and out into the containment. This eventually reduced the size of the bubble, but added to the hydrogen in the containment. By April 3, a hydrogen recombiner was in place outside the containment, and hydrogen concentration dropped gradually (2.3 percent, late p.m., April 1; 2.1 percent, early a.m., April 4). It was expected that the concentration would be brought down to 1 percent by about April 15.

- At press time, some coolant temperatures above the core were still in excess of 200 °C, requiring primary pressure to be maintained at about 6.9×10^6 Pa (100 psi). The approach to cold shutdown that was preferred as of April 6 was to continue cooling with pumped circulation until about April 11, and then convert to "natural circulation" in the primary system and solid water in the secondary. Use of the residual heat removal system (RHRS) was not actively being considered.

the core, 3.32×10^6 Ci in the coolant, and 0.235 Ci in the industrial waste treatment system; in all cases, I-131 accounts for at least 96 percent of the activity, and I-133 for the remainder. The industrial waste treatment system was continuing to be filled through the turbine building sump, and capacity was limited. Releases from this system to the Susquehanna River since the accident have stirred much public resentment.

Three plant employees were exposed to radiation beyond the 3 rem per quarter level by the end of the quarterly monitoring period on March 31. Dosages of 3.1, 3.4, and 3.8 rem were received when the workers tried to drain and secure the auxiliary building. At least 12 other workers received considerable doses below 3 rem.

Hitting home

Technical aspects aside, what established this as the most serious nuclear accident was its effect upon the daily lives of the public. For the first time, a problem in a nuclear power plant disrupted the personal and business activities of many thousands of people.

Initially, most of the residents in the area went about their daily routines, but this quickly changed. While some residents did continue to state they felt they were in no great danger, many others expressed feelings ranging from anger at the inconvenience caused by the situation to fear for their health and safety. Widespread distrust of the statements by utility spokesmen was reported. "I just don't believe them" was a typical response. Others expressed concerns for their property values and their businesses.

On Friday, March 30, Gov. Richard Thornburgh ordered several schools closed in the area of the plant and recom-

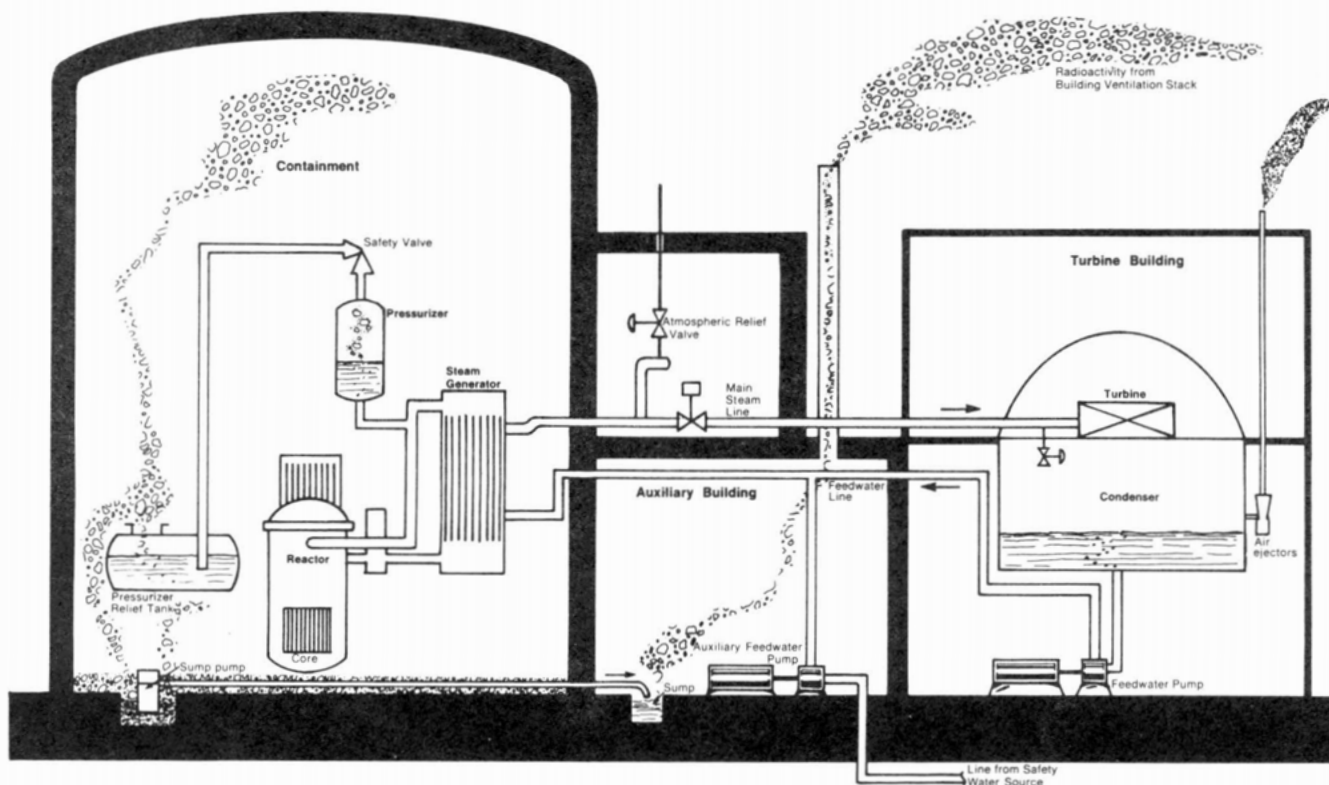
mended the evacuation of preschool children and pregnant women within five miles of the plant. Also, he urged people living within 10 miles to remain indoors. These actions were taken on the recommendation of NRC Chairman Joseph Hendrie and following an "unplanned and unexpected release" of radioactive gas. The following day, Thornburgh said it was no longer seen as necessary that people living within 10 miles of the plant remain indoors, but he still advised that pregnant women and preschool children move from the area five miles around the plant.

Also, plans were prepared for a general evacuation for everyone out to a distance of 20 miles from the plant. Thornburgh announced that a precautionary evacuation might be ordered should the efforts in bringing the reactor to a cold shutdown state be considered sufficiently risky to require evacuation. Such an evacuation was most discussed on March 30-31 and April 1, when the hydrogen "bubble" in the reactor was complicating efforts to cool down the core.

On Sunday, April 1, President Carter visited the site, with the reason for his visit interpreted widely as that of reassuring residents while preparing them for a general evacuation, if that became necessary. If it did, he said, the evacuation instructions should be followed "calmly and exactly." By April 2, definite progress was noted in removing the hydrogen bubble, and Thornburgh announced that a general evacuation would probably not be needed.

Estimates varied greatly about the number of people who moved out of the area, but civil defense officials said that of the 200 000 people living within 20 miles of the plant, an estimated 80 000 left over the weekend of March 31-April 1; 40 000 were still away on Tuesday, April 3; and

Simplified PWR Showing Three Mile Island Release Paths



30 000 to 35 000 had not yet returned on April 5. In addition, an undetermined number of businesses were closed.

Helping somewhat to alleviate the disgruntlement of the area people was the presence of American Nuclear Insurers, which set up an emergency claims office in Harrisburg. ANI staff members distributed checks to evacuees to cover their hotel and meal expenses, and by Tuesday, April 3, about \$200 000 had been paid out. A spokesman for ANI said that the pool of nuclear insurance firms had "no idea" how much would be paid out in such claims, and that ANI had "no estimates on either side" on property and liability claims. Prior to the TMI-2 situation, ANI had paid a total of only \$620 000 in claims since the insurance pools were formed in 1957.

On April 3 and 4, with the situation improving at the plant, and with people returning and some schools and businesses reopening, the area was starting to return to some semblance of normalcy. Still to be determined were just how permanent would be the loss of faith by the area residents in the plant's safety, and any adverse impact on the local economy.

The accident sharply changed the plans of the whole General Public Utilities Corporation group (which also includes Jersey Central Power and Light Company and Pennsylvania Electric Company). Even if the outcome is the most favorable for the utility—i.e., if TMI-2 can be repaired and returned to service at a tolerable cost—the expenditure in money and personnel will be sizable. The situation will not be helped if TMI-1, which was off line for routine maintenance at the time of the TMI-2 accident, is forced to remain out of service very long; TMI-1 has been a dependable, highly productive unit during its four and a half years of operation, and a prolonged outage will add replacement power costs to GPU's other worries.

Aware of its predicament, GPU moved on April 3 to suspend all construction work on new power plants (including the Forked River nuclear unit) and all but the most essential construction on existing facilities. Nonessential maintenance will be reduced or postponed wherever possible, and scheduled outages may be postponed.

Political reactions

At the political level, reactions came quickly, and, not unexpectedly, there were few to take up any defense of nuclear. On Thursday, March 29, the morning after the accident, all five NRC commissioners, along with top NRC aides, were called before the House Interior Committee's Subcommittee on Energy and the Environment (Rep. Morris K. Udall [D., Ariz.], chairman) to brief the committee on the accident. Reflecting the obvious concern of their constituents, the Congressmen were at times sharp in their questioning of NRC Chairman Hendrie and his colleagues. Hendrie was asked by Rep. James Weaver (D., Ore.), "How close did we come to the China Syndrome?" Hendrie replied, "We were nowhere near it, nowhere near it." The Congressmen persisted, "Could it happen?" Hendrie answered, "In principal, yes," but he insisted that the chances that it would happen were very small. Weaver indicated he was not assured by the NRC Chairman's responses.

Representative Udall did not hide his skepticism concerning the safety of nuclear power either at the hearing or on the same "Issues and Answers" program alluded to earlier, where he urged that America's reliance on nuclear power for the future be seriously questioned. He said that since

Other B&W units cleared to operate

Directed by the Nuclear Regulatory Commission to review their operations in light of the TMI-2 incident and to report within 10 days on the status of their plants and procedures, the operators of eight other Babcock & Wilcox reactors will be allowed to continue operating, this being judged "without undue risk to the public," as stated by Edson Case, NRC deputy director of nuclear reactor regulation at a public briefing on April 4. Case noted that the NRC would take whatever action might be necessary after the reports are received.

Of the eight plants, roughly the same but differing slightly (some have supplemental safety systems not found at TMI-2), only five are operating currently. These are: Rancho Seco, operated by Sacramento Municipal Utility District; the three Oconee units of Duke Power Company; and Crystal River-3 (Florida Power Corporation), scheduled for an outage later this month. The other three units are presently down for scheduled outages. These are: TMI-1; Unit 1 of Arkansas Nuclear One (Arkansas P&L); and Davis-Besse-1 (Central Area Power Coordination Group).

the country is now dependent on this source for no more than 10–12 percent of its electricity, it would not be too difficult to curtail future efforts in this direction and to shift to other alternatives. He said the people had been told that this type of accident would not happen, and now it has happened. Rasmussen later corrected this by saying that this type of event was among those covered in the Reactor Safety Study (WASH-1400). Rasmussen agreed with Udall that a thorough review of similar reactors would be necessary to prevent similar occurrences.

The NRC, in the meantime, has directed the operators of all nine Babcock & Wilcox reactors having operating licenses to review their facilities and procedures in light of the TMI-2 incident (see box). The Commission also, as part of its investigation of the incident, is setting up a special review group similar to the one established in the case of the Brown's Ferry fire.

Over and above these efforts by the NRC, Pennsylvania's Sen. Richard Schweiker (R.) has called for the formation of a Presidential commission to analyze "the full implications of the Three Mile Island accident" and has asked that this analysis include what role nuclear power should play in the future of U.S. electricity generation.

Other legislation doubtless will be generated from the hearings being conducted by various committees on both sides of Congress. Sen. Gary Hart (D., Colo.), chairman of the Subcommittee on Nuclear Regulation, said he plans to propose legislation that would strengthen federal oversight of all nuclear power plants. His legislation would put the government, rather than the utility, clearly in charge if and when a serious accident should occur. Hart suggested that all plants be monitored remotely by the NRC, possibly by satellite communication.

Somewhat along those same lines, President Carter signed almost immediately after the accident an executive order centralizing much of the federal emergency planning in a single agency, the Federal Emergency Management Agency. This agency combines the Defense Civil Preparedness Agency, the Federal Disaster Assistance Administration, the

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Federal Preparedness Agency, the Federal Insurance Administration, and the National Fire and Control Administration.

Actions were taken, too, at the state level. California Gov. Jerry Brown sent a telegram to the NRC after the accident urging that the Rancho Seco nuclear plant near Sacramento, a B&W unit, be ordered shut down until the Three Mile Island incident was fully studied and corrective measures could be taken.

A few brave souls in the public eye did make statements in defense of nuclear power—notably, Department of Energy Secretary James Schlesinger, who two days after the accident cited the “historic record” of nuclear power as

“excellent” and urged that the accident be viewed in proper perspective. He noted that the radiation exposures experienced were “very limited” and contended that nuclear power must continue to be “an essential element” in the nation’s drive for energy independence. Sen. J. Bennett Johnston (D., La.) was quoted soon after the accident as saying that it “could lead to an agonizing reappraisal of our use of nuclear power,” but adding that “if you’re going to have a viable economy, you’ve simply got no choice but to have nuclear power.” The Senator’s ambivalence clearly describes the quandary in which many public officials—and the American people—now find themselves with respect to nuclear power.

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