News & Comment

Postmortem on Three Mile Island

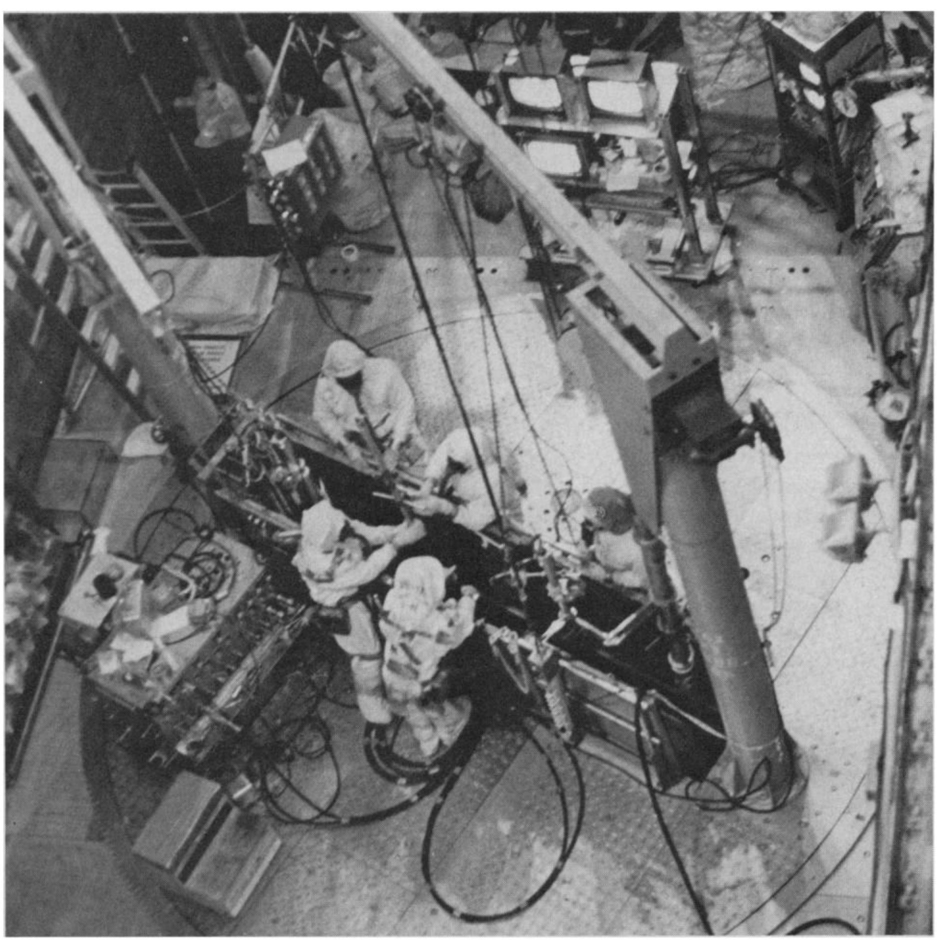
After 8 years and $1 billion, the cleanup is coming to an end. A mass of data has been produced but one nagging question remains: Why wasn't there core on the floor?

Harrisburg, Pennsylvania

For the past 2 years, men like Jack Bomgardner have been standing on top of the damaged nuclear reactor at Three Mile Island, peering into the radioactive murk beneath their protective booties. With his colleagues, Bomgardner is removing the damaged core of the Unit 2 reactor at Three Mile Island (TMI-2), a chore accomplished by chopping up radioactive boulders and fishing fuel pellets out of the water-filled reactor vessel. It is slow and frustrating work, says Bomgardner, made more difficult by the need to wear respirators and two layers of protective clothing. Apparently it is also difficult to peer through 30 feet of cloudy water and, with a tool set at the end of a 40-foot pole, to pick up a fuel pellet no bigger than the tip of one's little finger.

The end, however, is in sight. Sometime this month, work crews at TMI-2 are scheduled to remove the last of the 177 damaged fuel assemblies, exposing the lower grid of the vessel. And it is here, at "the bottom of the pot," that researchers hope to answer a nagging question: how close did the reactor vessel come to being breached during the accident of 28 March 1979? Or as one engineer who is evaluating the accident for the Department of Energy (DOE) put it: "Why wasn't there core on the floor?"

It is now known that conditions in the core were much more extreme than previously believed. Samples taken from the reactor vessel and examined at DOE's Idaho National Engineering Laboratory (INEL) reveal that at least 70% of the TMI-2's core was damaged, and between 35 and 45% of it actually melted during the accident, according to James Broughton, manager of the accident evaluation program for EG&G Idaho, the lead contractors at INEL. In addition, approximately 40,000 pounds of core material migrated to the bottom of the reactor during the accident. Many investigators are surprised that the reactor vessel maintained its integrity in the face of so great a challenge. "If you had a substantial core melt, why didn't it breach the vessel? After all, it's only carbon steel," says Gary Berna, manager of DOE's TMI-2 program in Idaho. Says Frank Standerfer, director of TMI-2 for GPU Nuclear, the utility that operates the two reactors on the island: "We're surprised the reactor vessel contained the accident."



GPU Nuclear

Working in the pot. *On the work platform directly on top of the damaged reactor. The men use long-handled tools to chop up radioactive boulders and pry apart previously molten fuel assemblies.*

Indeed, surprises have not been hard to find during the cleanup and defueling of TMI-2. "Essentially, every time they've gone into an area they hadn't been in before they've been surprised," says William Franz, an EG&G engineer who is in charge of storing TMI-2's waste at the Idaho site.

The first surprise set the mood. In the summer of 1982, before the top of the reactor vessel was even removed, a miniature video camera was squeezed through a 1.5-inch hole in the head of the vessel. It was called "Operation Quick Look," and its mission was to assess the damage to the core. Franz remembers being among the crowd that watched the live images of the camera's descent on closed circuit television. "The mood was one of shock," says Franz. There was a large open cavern 5 feet deep where the tops of the fuel assemblies should have been. Below the void was a bed of loose rubble.

Until that moment, most researchers believed that conditions in the core had never gotten hot enough to fracture fuel assemblies. After all, the control rods that plunge down into the reactor vessel from above were largely undamaged. Says Franz: "Nobody in the utility company wanted to believe there would be a void." But the void turned out to be the least of their problems. In February 1985, they jacked up the upper plenum, a 55-ton structure that sits on top of a reactor vessel like a lid on a boiling pot, and again lowered a small-diameter camera into the reactor, this time down a circuitous path that allowed the camera to reach the bottom of the vessel. Another eye popper: the lower region was full of rubble, too, as much as 20 tons of it. Even worse, there was the first evidence that some of the fuel was once molten. It takes temperatures of 5100°F to melt uranium dioxide. Suddenly, defueling the reactor began to look like an extremely cumbersome task, for it is one thing to pull largely undamaged fuel assemblies out of the vessel and quite another to pry apart previously molten lumps of uranium dioxide and zirconium alloy.

GPU Nuclear officials were faced with an enormous mess: not only were radioactive fission products contaminating sumps, pumps, and pipes throughout the system, as well as the basements of both the reactor and auxiliary buildings, but the reactor core itself was a highly radioactive pile of previously molten rubble. A few months after the accident in 1979, GPU Nuclear officials were predicting that the job could be done in 2 or 3 years at a cost of $140 million. By 1989, when defueling and most cleanup activities are expected to be complete, the enterprise will have consumed $965 million. Explains Standerfer: "Each new piece of information has proved that the next step of the cleanup would be more difficult than the last."

Removing the damaged fuel from the core has proved to be the most difficult and delicate part of the cleanup. Seven days a week, five times a day, small teams of four or five defuelers enter a special locker room in the Unit 2 turbine building. Assisted by attendants, each man is swaddled in two anticontamination suits and draped with plastic smocks. They wear several pairs of gloves, which they change every 15 minutes. Often the men wear rubber vests filled with ice, a crude but effective way to keep them from overheating. Finally, they are connected to battery-powered respirators that gently feed air into their lungs.

Once through the reactor building's airlock, the men walk quickly to the work platform, for it is here that they are best shielded from the high background radiation. Ambient levels of radiation on the platform expose the men to between 10 and 20 millirems per hour, which is equivalent to getting a chest x-ray every hour. Sometimes, particularly when a piece of fuel works its way into a tool flange and is lifted from the water, "the rad levels can really start screaming," explains Bomgardner, an auxiliary operator who has been defueling the reactor since the project began in November 1985. According to Hans Behling, GPU Nuclear's manager of health, the average defueler receives about 2000 millirems a year, though some men approach the limit of 5000 millirems per year set by the federal government. As a comparison, the estimated annual exposure to the average American is 360 millirems, of which 200 millirems come from radon gas, according to a recent study by the National Council on Radiation Protection and Measurements. William Travers, the Nuclear Regulatory Commission (NRC) official who is overseeing the cleanup, says GPU Nuclear gets "high marks" for adhering to radiological safety standards.

To keep radiation exposures down, the men are allowed to work on the defueling platform only 1 week in 6. The shifts last less than 4 hours. In addition, the platform is made of steel and lead, with only an 18-inch wide work slot through which the men lower their tools into the water that covers the damaged core.

"Each new piece of information has proved that the next step of the cleanup would be more difficult than the last," says one official from GPU Nuclear.

The tools for defueling are familiar objects: vice grips, jaws, pliers, shovels, buckets, chisels, and cutting torches. Some are hydraulic; others are manual. What is unusual about them is the fact that they are affixed to the ends of 40-foot aluminum or steel poles. A pair of underwater television cameras and camera lights have been positioned in the core. As one man moves his tool, another watches a television monitor and gives coordinates. Because of the respirators, the men must communicate by throat mikes, which are constantly going on the fritz. Bomgardner reports that the core is a strange world, complete with its own eddies and currents twisting around once molten lumps of fuel. It is easy to lose things and become disoriented. Eventually, everything must be brought near the surface and placed into fuel canisters that have an opening of only 8.5 inches. What is too big to cram into the cans, the men chop up with an air-driven chisel that uses a 12-foot bit. The men refer to their job as "working in the pot." It seems an apt metaphor for the collision between high and low technologies, between the nuclear engineers modeling on their computers and the hourly employees smashing up radioactive rocks with big sticks.

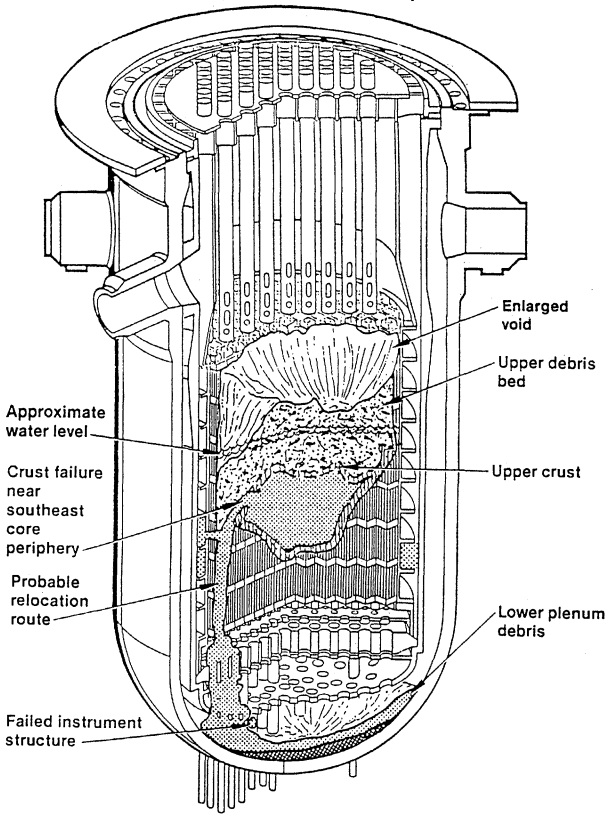
One reason for the slow pace during the early months of defueling was that after a few hours work, the water became so cloudy that the men had to operate by feel. The low visibility was caused by fine sediment and by the hardy organisms that thrived in the reactor vessel. "The reactor was just like a stagnant pond in summertime," says Gordon Tombs, GPU Nuclear's earnest public relations man. The decaying fuel assemblies keep the water heated to a tepid 80°F, and the underwater camera lights allow for photosynthesis, making the core a suitable habitat for many species of algae, fungi, yeast, and bacteria. Particularly impressive are the bacteria that feed on the carbon-rich hydraulic fluid that leaks from the tools during defueling. The bug problem was solved by dumping hydrogen peroxide into the soup. The problem of the fine sediment was solved by adding a coagulant that binds the tiny grains onto larger, heavier particles.

After removing the upper debris bed and killing the bugs, the cleanup team discovered it had another problem. Immediately below the loose rubble was something hard. A decision was made to drill borings through the full length of the reactor vessel. DOE provided a special drilling rig, complete with diamond-coated tungsten carbide bits. EG&G agreed to take ten core borings to Idaho for analysis. As the core borings were being examined, the large, previously molten mass was broken apart by the same drilling rig used to take the core borings. Like everything at Three Mile Island, this task had a name. They called it "Operation Swiss Cheese," because they made 466 borings in the molten mass, which left behind material ranging in size from grains of sand to 1100-pound boulders.

What has evolved during the defueling is an extremely detailed scenario of what happened inside the reactor during the first 226 minutes of the accident. According to the current scenario formulated by Broughton and his colleagues, the accident went like this:

- During the first 100 minutes, the core slowly lost its water. A valve was stuck open and operators misread the water and pressure levels in the reactor. Pressure dropped and the core cooled. It is important to remember that at this point things are happening relatively slowly, says Broughton.
- Between 130 and 140 minutes, the water fell to its lowest level. The exposed core was heating up, cooled only by the

Hypothesized Core Damage Configuration (226 Minutes)



EG&G Idaho, Inc.

Migrating fuel

During the accident, the tops of the fuel assemblies fractured and cracked, forming a void and a bed of loose rubble. Below, a stream of molten core makes its way to the bottom of the reactor vessel.

rising steam. The zirconium alloy cladding that is wrapped around the fuel pellets began to balloon and rupture.

■ Between 150 and 160 minutes, the cladding started to oxidize. Burning zirconium alloy was running down the fuel assemblies. Events that started in the hottest part of the core—the center—were migrating downward and outward. A hard crust was forming just above the water level.

■ At 173 minutes, a partially molten mixture of zirconium dioxide and uranium dioxide was heading toward the bottom of the reactor.

■ Between 175 and 180 minutes, the water level began to rise. The fractured fuel assemblies at the top of the core started to fragment. A void appeared where the top of the splintered fuel assemblies used to be. "The assemblies had overheated and shattered like a hot glass held under cold water," reports Ken Pastor, chief of the defueling operation for GPU Nuclear. The crust that formed just above the water level seemed to hold the molten mass in place.

■ At 224 minutes, with the water still rising, the fuel assemblies were really beginning to crack, enlarging the void and creating the bed of loose rubble. In the center of the core, the large molten mass of fuel and cladding was being supported by a 6-inch crust.

■ At 226 minutes, it happened. The molten mass broke free at the southeast corner of the reactor. On its way to the bottom of the reactor, a side stream of fuel burned through what is called the core former wall, an internal structure that gives the core its hexagonal configuration, even though the reactor vessel itself is round. The metal and ceramic mixture reached the bottom of the vessel very quickly. "The main relocation event occurred in a minute or less," says Broughton.

At this point, there are an estimated 20 tons of previously molten core and core debris on the bottom on the reactor vessel. To remove the rubble, the work crews must first remove the lower head, a series of five steel plates that were designed to support the fuel assemblies and to distribute the flow of water through the core. Researchers suspect that there is a 1000-pound puddle of silver at the bottom of the reactor. The silver would have come from diagnostic tools that melted during the accident. Of course, there could still be surprises. "Everybody who has tried to project what they'll find has been wrong," says Travers of the NRC. Says GPU Nuclear's Pastor: "Every time we hope something goes our way, it doesn't. So I assume we'll find silver at the bottom."

After the vessel is scraped clean, Broughton wants to bore into the bottom of the reactor head. "The questions we want to answer are: Was there a chemical interaction between the nonfuel material and the lower head? And was there a thermal interaction? How hot did it get?" says Broughton. "It's still a possibility that the vessel was breached," adds Travers.

At present, the best guess as to why the vessel did not breach lies in the accident scenario. "Having water in the lower head was key. That cannot be overstressed," says Broughton. "The good news is that a very small amount of water can serve to cool a severely damaged core, that a relatively small amount of water mitigated the accident," says Travers. Also, the rapidly cooling molten core itself could have served as an insulating layer, since the mixture that reached the bottom was ceramic. "It may have formed a kind of protective crucible," says Standerfer. They will not know until they do the drilling, a procedure that GPU Nuclear has not yet agreed to.

GPU Nuclear is presently negotiating with the NRC over how clean the cleanup of TMI-2 has to be. The utility proposes leaving no more than 70 kilograms of fuel, the minimum quantity required for criticality, in any one neutronic area. What this means is that there could be 70 kilograms here and there, though the remaining uranium dioxide must be far enough apart to prevent a chain reaction from happening.

What will become of TMI-2 has not yet been officially announced. Standerfer says refurbishing the reactor is still a possibility, although it would be impossible if DOE drills holes into the bottom of the reactor head. Almost everyone agrees that TMI-2 will never operate again. Instead, the reactor will be placed in what GPU Nuclear is calling "Post Defueling Monitored Storage," which is akin to putting the reactor in mothballs. A skeletal staff will continue to operate vents and filters while monitoring radiation levels.

The utility cannot leave the fuel there indefinitely. Eventually, sometime around 2010 when the now operating Unit 1 reactor at Three Mile Island is decommissioned, they'll also disassemble Unit 2. "Eventually, they're going to have to get it all," says Travers. "They are leaving behind a considerable amount of contamination."

Travers is referring in particular to the basement of the reactor building, which was flooded with nearly 1 million gallons of contaminated water during the accident. No human has ventured into the basement since the accident occurred. The place is the sole domain of a pair of robots that roll around the area blasting the walls with high-pressure water flushes, chipping off radioactive concrete, and vacuuming up the sludge, silt, and concrete chips that cover the floor. More than 90% of the radioactivity is collected in the concrete walls, according to M. D. Pavelek, the Bechtel National engineer whose job is to decontaminate the basement.

Pavelek's two robots report the highest radiation readings come from the concrete block walls that surround a stairway and an elevator. To confirm a direct correlation between the density of the concrete and its radioactivity, Pavelek and his colleagues performed a simple experiment. They took a couple of concrete blocks, stuck them in a wash basin, and poured hot coffee over them. "In a minute, the coffee was in the wash basin," Pavelek reports. "We confirmed something we knew: concrete block is very porous stuff." To reduce the contamination, they have experimented with blasting the concrete block with high-pressure, high-temperature water jets, but unfortunately the wall is permeated with cesium. Pavelek says they might try to flush the concrete block with water from the top or fill the block wall with concrete, hoping the cesium eventually leaches out. A final possibility calls for instructing the robots to destroy the wall. But this would take months and cost as much as $5 million.

Another nagging problem remains. How does GPU Nuclear get rid of 2.1 million gallons of water that was contaminated during the accident and cleanup? The company has proposed three options. They can dilute it and dump it in the Susquehanna River. They can make concrete with it and bury the blocks in an industrial landfill on the island. Or they can slowly evaporate the water and take the residue to a commercial dump. GPU Nuclear says that none of the options would pose any significant environmental hazard. All would meet federal regulations. And all three would involve relatively low-level releases of tritium, cesium-137, and strontium-90. Because the first two options are so politically sensitive, GPU Nuclear is trying to convince the NRC and a vocal community of antinuclear activists to let them evaporate the water. A suit and a number of hearings are pending. Travers estimates that it will take at least a year before the parties agree what GPU Nuclear will do with its water. If the company goes with evaporation, it will take another 2 years and $6 million.

After it is all over, after the defueling and cleanup are complete, after the basement is scrubbed and the contaminated water disposed of, there will still be one lingering legacy from Three Mile Island: the fuel.

For now, this problem has been passed on to the national engineering laboratory outside Idaho Falls, Idaho. Once a naval gunnery range, the laboratory covers 890 square miles of lonely, sagebrush desert. Over the years, the site has supported 52 experimental nuclear reactors, including the first reactor to produce electricity; in this case for the little town of Arco, Idaho. In one corner of INEL is a place called Test Area North, the site of the infamous program to build nuclear-powered jets that was axed by the Kennedy Administration in the early 1960s. A few of the old jet engines are rusting in the desert at Test Area North. It is here that the waste from TMI-2 arrives by railcar, transported in large casks that look like oversized barbells. Officially, DOE maintains that it takes the fuel from GPU Nuclear "for analysis and storage," though there is a lot more storage going on than analysis. Only a minute fraction of the damaged core is actually ever examined.

The rest of it is unloaded from its shipping casks by remote control in the largest known "hot shop" in the world. The fuel canisters loaded in TMI-2 are then stacked together in groups of six and placed very gently in a storage pool. And there the canisters will sit until a national nuclear waste repository is constructed at an as yet undetermined site. "We prepared to hang on to it for 30 years," says Franz of EG&G. "After that, who knows?" ■

William Booth

Apples, Frogs, and Animal Rights

Apple Computer has withdrawn a controversial television ad after it stirred up criticism from those who saw it as animal rights propaganda.

The ad, which Apple pulled last month, featured a California teenager who became a cause célèbre last spring when she refused to dissect a frog in her sophomore biology class at Victor Valley High School in Victorville. Jenifer Graham, a 16-year-old vegetarian who opposes any use of animals, received a B instead of her usual A. With the support of animal rights groups, she brought suit in Los Angeles federal court claiming the school had acted unconstitutionally in not allowing her an alternative means of learning the material.

Apple Computer, which markets a pathology program called "Operation Frog" was attracted by the extensive local newspaper and television coverage of the story. Jenifer agreed to star in an ad for Apple with the following text:

"Last year in my biology class, I refused to dissect a frog. I didn't want to hurt a living thing. I said I would be happy to do it on an Apple computer. That way, I can learn and the frog lives. But that got me into a lot of trouble, and I got a lower grade. So this year, I'm using my Apple II to study something entirely new—constitutional law."

This message was greeted with great alarm by the California Biomedical Research Association, which represents most of the major research institutions in the state. In late October the association circulated an "action alert" urging people to write in protest to Apple president John Sculley. Executive director Sandra E. Bressler wrote Sculley that the ad was "in very poor taste and offensive" to scientific educators, that it "advances the cause of fanatics," and that Apple was contributing to "dangerous and simple-minded thinking."

Apple, according to its marketing director Bruce Mowery, had no intention of taking a stand on animal research and did not realize the ad would be controversial. Mowery says the company received "a number of letters," both pro and con, and realized "there was confusion as to what the message of the commercial was."

The fuss illustrates how little it takes to stir up this volatile issue. Barbara Orlans, director of the Scientists Center for Animal Welfare and an authority on animal use in the schools, says she was "amazed" that researchers would feel threatened by the ad, which merely illustrates an ongoing trend—"there is quite a lot of getting away from dissection in precollege education." Orlans contends that dissection in the classroom "is not essential or desirable for the emotionally immature" and those not oriented to a career in science.

Practically anything to do with animals in research is inflammatory these days, however. Carol Scheman of the Association of American Universities (AAU) points out that the ad, in effect, was "a cute marketable commercial for antivivisection." The AAU and other organizations are very concerned about the reduction of animal use that is occurring in all levels of education. Frankie Trull of the Foundation for Biomedical Research says that cases have even arisen where medical and veterinary students have refused to do experimental surgery on animals.

If California is any indication, antivivisectionist sentiment is still on the rise. The state legislature will soon be voting on a measure introduced last year that would give all students in public and private schools, colleges, and universities the right to refuse to dissect or harm an animal as part of a course of instruction. ■ **Constance Holden**