Report Of
The President's Commission On

THE ACCIDENT AT THREE MILE ISLAND

The Need For Change:
The Legacy Of TMI

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October 1979 Washington, D.C.

The President's Commission On

THE ACCIDENT AT TMI

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President's Commission
on the Accident at Three Mile Island
2100 M Street, NW Washington, DC 20037

October 30, 1979

The President
The White House
Washington, D.C. 20500

Dear Mr. President:

In accordance with Executive Order Number 12130, we hereby transmit to you the final report of the President's Commission on the Accident at Three Mile Island.

Faithfully yours,

John G. Kemeny

John G. Kemeny
Chairman

Bruce Babbitt

Bruce Babbitt

Harry McPherson

Harry C. McPherson

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PREFACE

THE CHARGE TO THE COMMISSION

On March 28, 1979, the United States experienced the worst accident in the history of commercial nuclear power generation. Two weeks later, the President of the United States established a Presidential Commission. The President charged the 12-member Commission as follows:

"The purpose of the Commission is to conduct a comprehensive study and investigation of the recent accident involving the nuclear power facility on Three Mile Island in Pennsylvania. The Commission's study and investigation shall include:

(a) a technical assessment of the events and their causes; this assessment shall include, but shall not be limited to, an evaluation of the actual and potential impact of the events on the public health and safety and on the health and safety of workers;

(b) an analysis of the role of the managing utility;

(c) an assessment of the emergency preparedness and response of the Nuclear Regulatory Commission and other federal, state, and local authorities;

(d) an evaluation of the Nuclear Regulatory Commission's licensing, inspection, operation, and enforcement procedures as applied to this facility;

(e) an assessment of how the public's right to information concerning the events at TMI was served and of the steps which should be taken during similar emergencies to provide the public with accurate, comprehensible, and timely information; and

(f) appropriate recommendations based upon the Commission's findings."

PREFACE

THE ACCIDENT

At 4:00 a.m. on March 28, 1979, a serious accident occurred at the Three Mile Island 2 nuclear power plant near Middletown, Pennsylvania. The accident was initiated by mechanical malfunctions in the plant and made much worse by a combination of human errors in responding to it. (For details see "Account of the Accident" within this volume.) During the next 4 days, the extent and gravity of the accident was unclear to the managers of the plant, to federal and state officials, and to the general public. What is quite clear is that its impact, nationally and internationally, has raised serious concerns about the safety of nuclear power. This Commission was established in response to those concerns.

WHAT WE DID

The investigation of the Commission was carried out by our able and hard-working staff. We also had the help of a number of consultants and commissioned several studies. It is primarily due to the work of the staff that we accomplished the following.

We examined with great care the sequence of events that occurred during the accident, to determine what happened and why. We have attempted to evaluate the significance of various equipment failures as well as the importance of actions (or failures of actions) on the parts of individuals and organizations.

We analyzed the various radiation releases and came up with the best possible estimates of the health effects of the accident. In addition, we looked more broadly into how well the health and safety of the workers was protected during normal operating conditions, and how well their health and safety and that of the general public would have been protected in the case of a more serious accident.

We conducted an in-depth examination of the role played by the utility and its principal suppliers. We examined possible problems of organization, procedures, and practices that might have contributed to the accident. Since the major cause of the accident was due to inappropriate actions by those who were operating the plant and supervising that operation, we looked very carefully at the training programs that prepare operators and the procedures under which they operate.

As requested by the President, we examined the emergency plans that were in place at the time of the accident. We also probed the responses to the accident by the utility, by state and local governmental agencies in Pennsylvania, and by a variety of federal agencies. We looked for deficiencies in the plans and in their execution in order to be able to make recommendations for improvements for any future accident. In this process we had in mind how well the response would have worked if the danger to public health had been significantly greater.

We examined the coverage of the accident by the news media. This was a complex process in which we had to separate out whether errors in media accounts were due to ignorance or confusion on the part of the official sources, to the way they communicated this information to the media, or to mistakes committed by the reporters themselves. We examined what sources were most influential on the people who needed immediate information, and how well the public was served by the abundant coverage that was provided. We also attempted to evaluate whether the coverage tended to exaggerate the seriousness of the accident either by selectively using alarming quotes more than reassuring ones, or through purposeful sensationalism.

Finally, we spent a great deal of time on the agency that had a major role in all of the above: the Nuclear Regulatory Commission. The President gave us a very broad charge concerning this agency. We therefore tried to understand its complex structure and how well it functions, its role in licensing and rulemaking, how well it carries out its mission through its inspection and enforcement program, the role it plays in monitoring the training of operators, and its participation in the response to the emergency, including the part it played in providing information to the public.

We took more than 150 formal depositions and interviewed a significantly larger number of individuals. At our public hearings we heard testimony under oath from a wide variety of witnesses. We collected voluminous material that will fill about 300 feet of shelf-space in a library. All of this material will be placed into the National Archives. The most important information extracted from this in each of the areas will appear in a series of "Staff Reports to the Commission."

Based on all of this information, the Commission arrived at a number of major findings and conclusions. In turn, these findings led the Commission to a series of recommendations responsive to the President's charge.

At the beginning of this volume will be found an overview of our investigation, followed by those findings and recommendations which commanded a significant consensus among the members of the Commission. Each recommendation was approved by a majority of Commissioners.

WHAT WE DID NOT DO

It is just as important for the reader to understand what the Commission did not do.

Our investigation centered on one accident at one nuclear power plant in the United States. While acting under the President's charge, we had to look at a large number of issues affecting many different organizations; there are vast related issues which were outside our charge, and which we could not possibly have examined in a 6-month investigation.

We did not examine the entire nuclear industry. (Although, through our investigation of the Nuclear Regulatory Commission, we have at least some idea of the standards being applied to it across the board.) We have not looked at the military applications of nuclear energy. We did not consider nuclear weapons proliferation. We have not dealt with the question of the disposal of radioactive waste or the dangers of the accumulation of waste fuel within nuclear power plants adjacent to the containment buildings. We made no attempt to examine the entire fuel cycle, starting with the mining of uranium. And, of course, we made no examination of the many other sources of radiation, both natural and man-made, that affect all of us.

We have not attempted to evaluate the relative risks involved in alternate sources of energy. We are aware of a number of studies that try to do this. We are also aware that some of these studies are subjects of continuing controversy.

We did not attempt to reach a conclusion as to whether, as a matter of public policy, the development of commercial nuclear power should be continued or should not be continued. That would require a much broader investigation, involving economic, environmental, and political considerations. We are aware that there are 72 operating reactors in the United States with a capacity of 52,000 megawatts of electric energy. An additional 92 plants have received construction permits and are in various stages of construction. If these are completed, they will roughly triple the present nuclear capacity to generate electricity. This would be a significant fraction of the total U.S. electrical generating capacity of some 600,000 megawatts. In addition, there are about 200 nuclear power plants in other countries throughout the world.

Therefore, the improvement of the safety of existing and planned nuclear power plants is a crucial issue. It is this issue that our report addresses, those changes that can and must be made as a result of the accident -- the legacy of Three Mile Island.

ACCOUNT OF THE ACCIDENT

PROLOGUE

On Wednesday, March 28, 1979, 36 seconds after the hour of 4:00 a.m., several water pumps stopped working in the Unit 2 nuclear power plant on Three Mile Island, 10 miles southeast of Harrisburg, Pennsylvania. 1/ Thus began the accident at Three Mile Island. In the minutes, hours, and days that followed, a series of events -- compounded by equipment failures, inappropriate procedures, and human errors and ignorance -- escalated into the worst crisis yet experienced by the nation's nuclear power industry.

The accident focused national and international attention on the nuclear facility at Three Mile Island and raised it to a place of prominence in the minds of hundreds of millions. For the people living in such communities as Royalton, Goldsboro, Middletown, Hummelstown, Hershey, and Harrisburg, the rumors, conflicting official statements, a lack of knowledge about radiation releases, the continuing possibility of mass evacuation, and the fear that a hydrogen bubble trapped inside a nuclear reactor might explode were real and immediate. Later, Theodore Gross, provost of the Capitol Campus of Pennsylvania State University located in Middletown a few miles from TMI, would tell the Commission:

> Never before have people been asked to live with such ambiguity. The TMI accident -- an accident we cannot see or taste or smell . . . is an accident that is invisible. I think the fact that it is invisible creates a sense of uncertainty and fright on the part of people that may well go beyond the reality of the accident itself.2/

The reality of the accident, the realization that such an accident could actually occur, renewed and deepened the national debate over nuclear safety and the national policy of using nuclear reactors to generate electricity.

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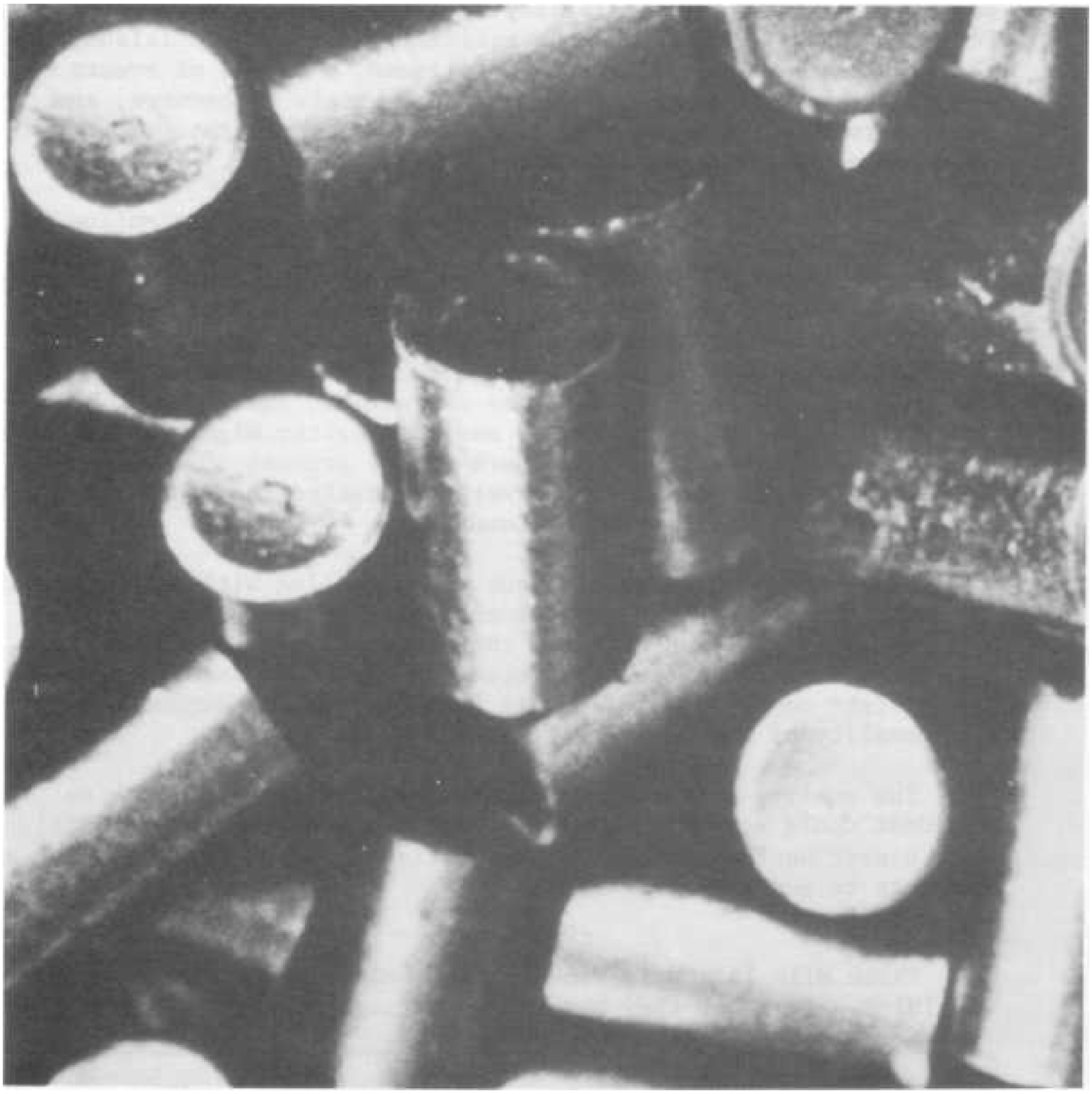
Three Mile Island is home to two nuclear power plants, TMI-1 and TMI-2. Together they have a generating capacity of 1,700 megawatts,

Photo at left: Goldsboro, Pennsylvania, March 28, 1979.

Simulated fuel pellets. The actual pellets are molded uranium oxide and are stacked one atop another inside the fuel rods. Each pellet is about one inch tall and less than a half-inch wide.



enough electricity to supply the needs of 300,000 homes. The two plants are owned jointly by Pennsylvania Electric Company, Jersey Central Power & Light Company, and Metropolitan Edison Company, and operated by Met Ed. These three companies are subsidiaries of General Public Utilities Corporation, an electric utility holding company headquartered in Parsippany, New Jersey.3/

Each TMI plant is powered by its nuclear reactor. A reactor's function in a commercial power plant is essentially simple -- to heat water. The hot water, in turn, produces steam, which drives a turbine that turns a generator to produce electricity. Nuclear reactors are a product of high technology. In recent years, nuclear facilities of generating capacity much larger than those of earlier years -- including TMI-1 and TMI-2 -- have gone into service.4/

A nuclear reactor generates heat as a result of nuclear fission, the splitting apart of an atomic nucleus, most often that of the heavy atom uranium. Each atom has a central core called a nucleus. The nuclei of atoms typically contain two types of particles tightly bound together: protons, which carry a positive charge, and neutrons, which have no charge. When a free neutron strikes the nucleus of a uranium atom, the nucleus splits apart. This splitting -- or fission -- produces two smaller radioactive atoms, energy, and free neutrons. Most of the energy is immediately converted to heat. The neutrons can strike other uranium nuclei, producing a chain reaction and continuing the fission process. Not all free neutrons split atomic nuclei. Some, for example, are captured by atomic nuclei. This is important, because some elements, such as boron or cadmium, are strong absorbers of neutrons and are used to control the rate of fission, or to shut off a chain reaction almost instantaneously.5/

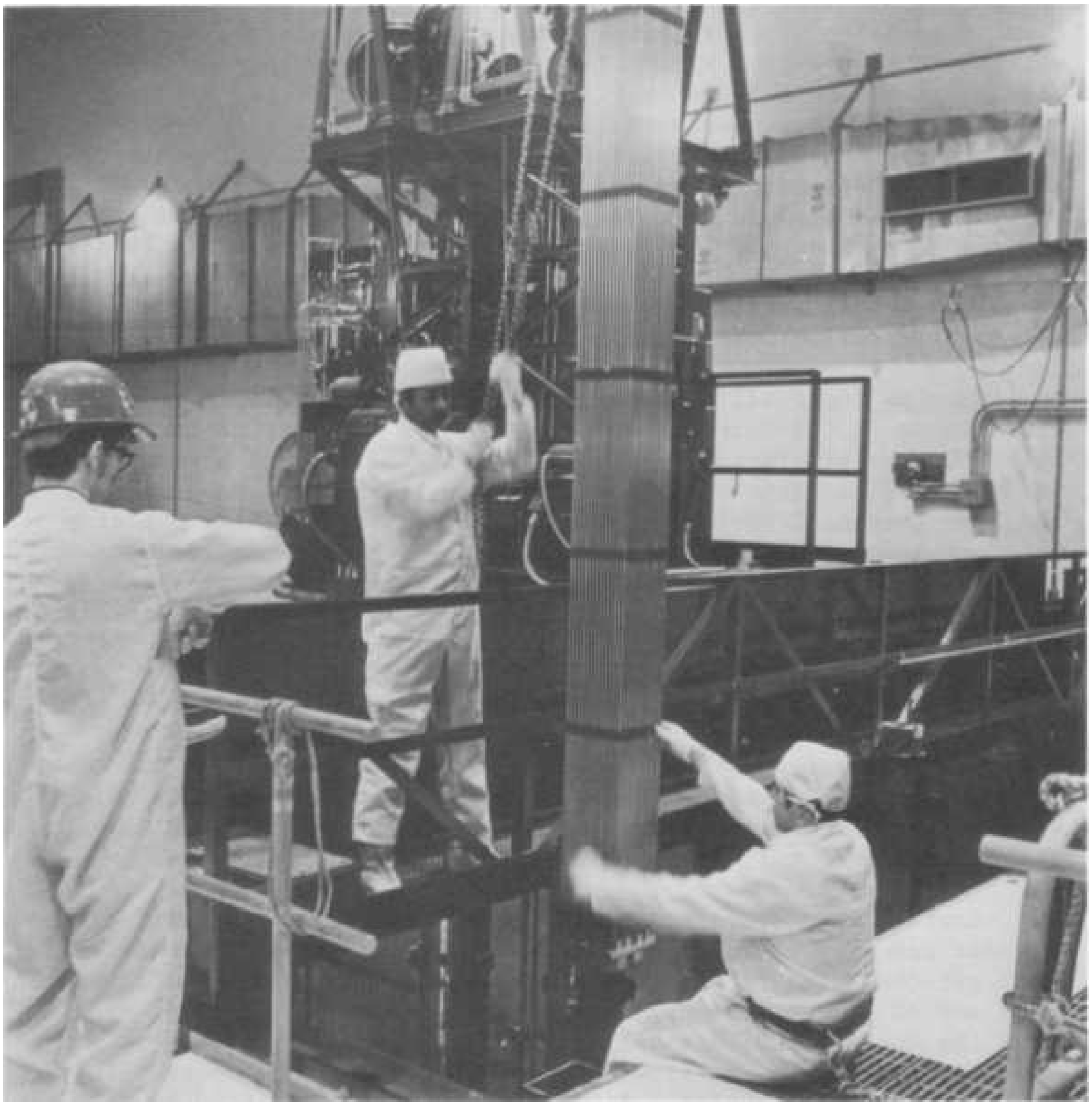
Uranium fuels all nuclear reactors used commercially to generate electricity in the United States. At TMI-2, the reactor core holds some 100 tons of uranium. The uranium, in the form of uranium oxide, is molded into cylindrical pellets, each about an inch tall and less than half-an-inch wide. The pellets are stacked one atop another inside fuel rods. These thin tubes, each about 12 feet long, are made of Zircaloy-4, a zirconium alloy. This alloy shell -- called the "cladding" -- transfers heat well and allows most neutrons to pass through.6/

TMI-2's reactor contained 36,816 fuel rods -- 208 in each of its 177 fuel assemblies. A fuel assembly contains not only fuel rods, but space for cooling water to flow between the rods and tubes that may contain control rods or instruments to measure such things as the temperature inside the core. TMI-2's reactor has 52 tubes with instruments and 69 with control rods.7/

Control rods contain materials that are called "poisons" by the nuclear industry because they are strong absorbers of neutrons and shut off chain reactions. The absorbing materials in TMI-2's control rods are 80 percent silver, 15 percent indium, and 5 percent cadmium. When the control rods are all inserted in the core, fission is effectively blocked, as atomic nuclei absorb neutrons so that they cannot split other nuclei. A chain reaction is initiated by withdrawing the control rods. By varying the number of and the length to which the control rods are withdrawn, operators can control how much power a plant produces. The control rods are held up by magnetic clamps. In an emergency, the magnetic field is broken and the control rods, responding to gravity, drop immediately into the core to halt fission. This is called a "scram."

The nuclear reactors used in commercial power plants possess several important safety features. They are designed so that it is impossible for them to explode like an atomic bomb. The primary danger from nuclear power stations is the potential for the release of radioactive materials produced in the reactor core as the result of fission. These materials are normally contained within the fuel rods.

A fuel rod assembly, containing 208 individual fuel rods, being inserted into the core of TMI-1.



Damage to the fuel rods can release radioactive material into the reactor's cooling water and this radioactive material might be released to the environment if the other barriers -- the reactor coolant system and containment building barriers -- are also breached.8/

A nuclear plant has three basic safety barriers, each designed to prevent the release of radiation. The first line of protection is the fuel rods themselves, which trap and hold radioactive materials produced in the uranium fuel pellets. The second barrier consists of the reactor vessel and the closed reactor coolant system loop. The TMI-2 reactor vessel, which holds the reactor core and its control rods, is a 40-foot high steel tank with walls 8-' inches thick. This tank, in turn, is surrounded by two, separated concrete-and-steel shields, with a total thickness of up to 9-/ feet, which

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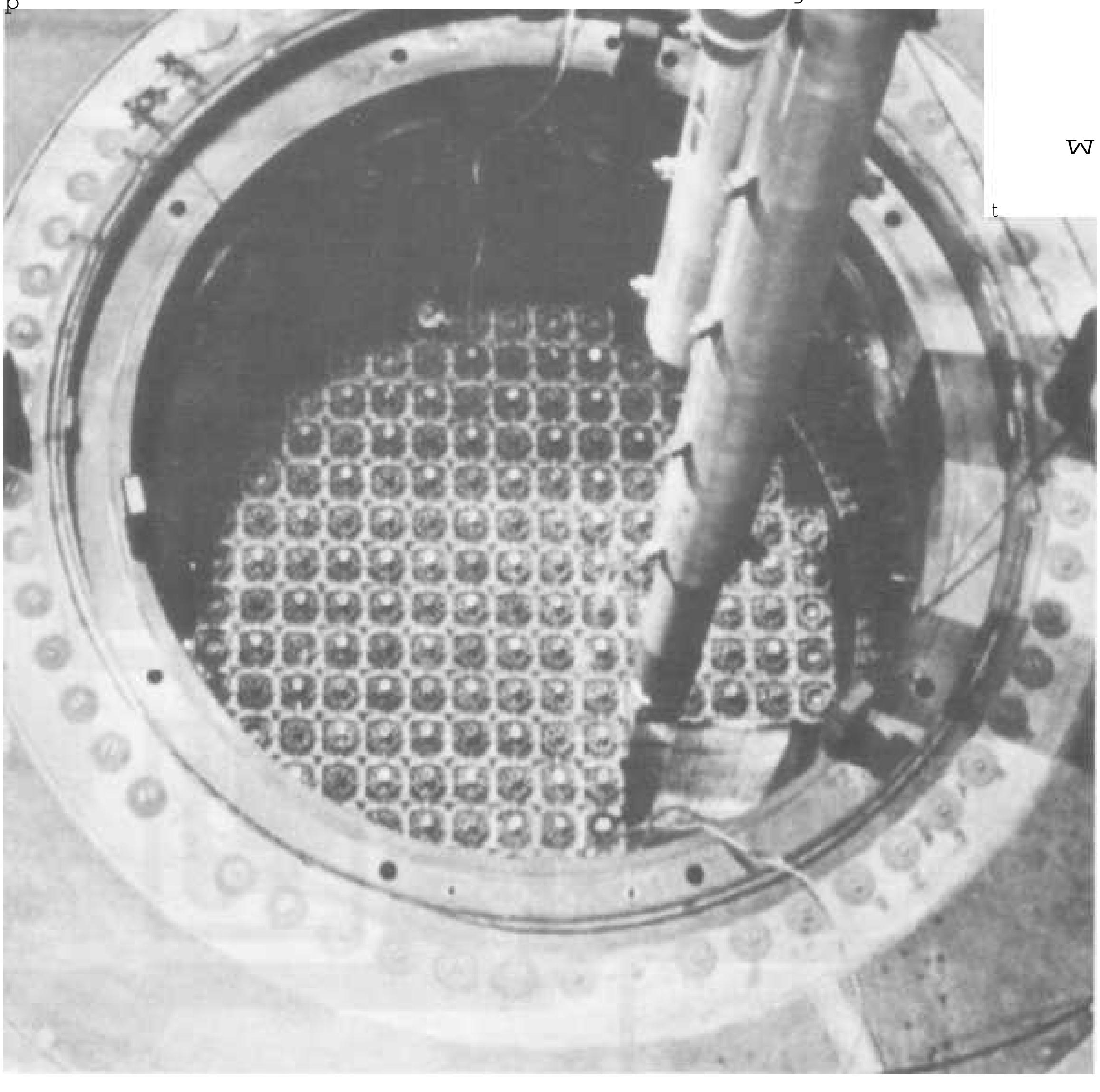
View of TMI-1's core taken from about 50 feet above the core. Each fuel rod assembly fits into one of the squares in the core's Qrid.



absorb radiation and neutrons emitted from the reactor core. Finally, all this is set inside the containment building, a 193-foot high, reinforced-concrete structure with walls 4 feet thick.9/

To supply the steam that runs the turbine, both plants at TMI rely on a type of steam supply system called a pressurized water reactor. This simply means that the water heated by the reactor is kept under high pressure, normally 2,155 pounds per square inch in the TMI-2 plant.

In normal operations, it is important in a pressurized water reactor that the water that is heated in the core remain below "saturation" -- that is, the temperature and pressure combination at which water boils and turns to steam. In an accident, steam formation

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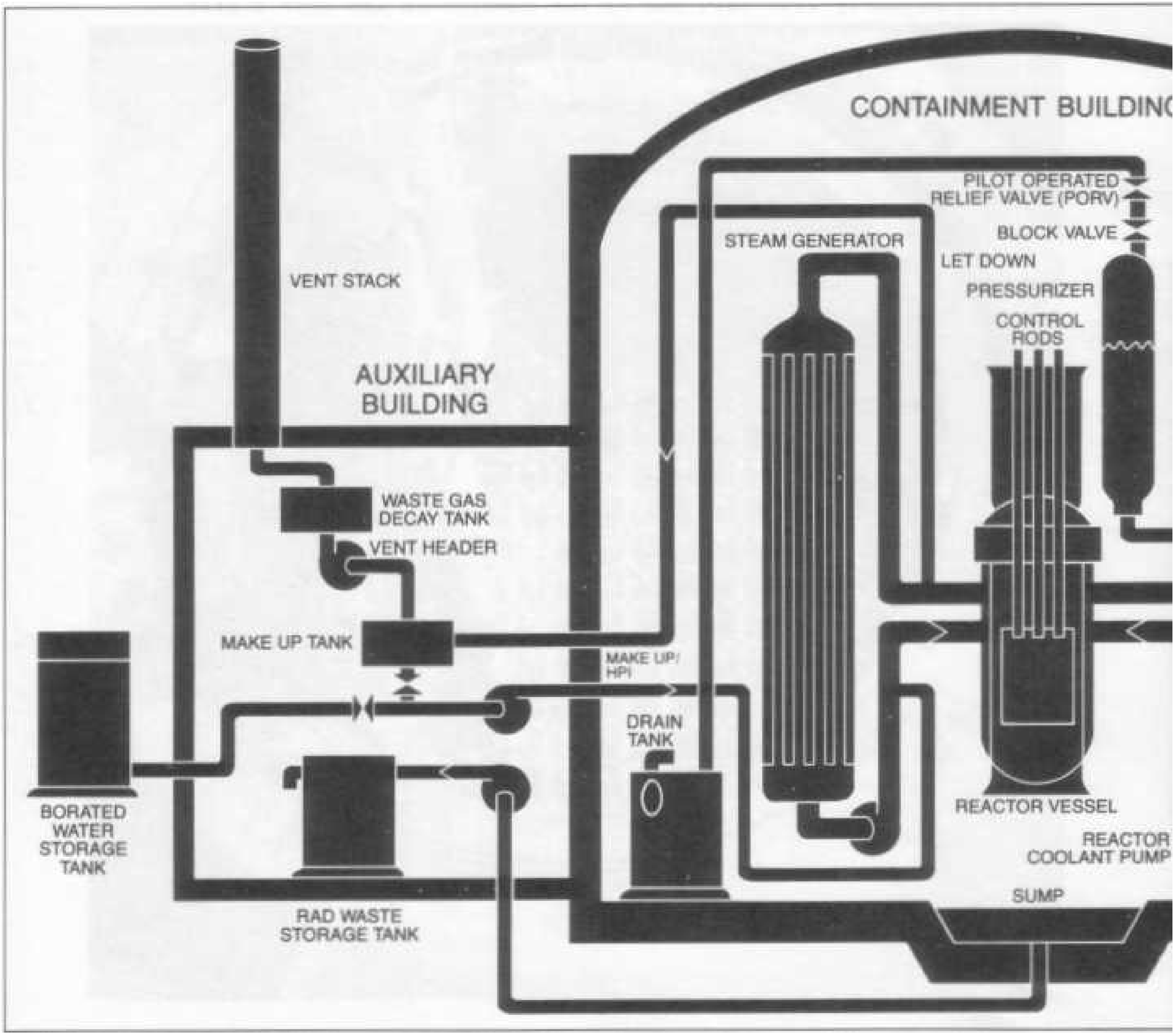
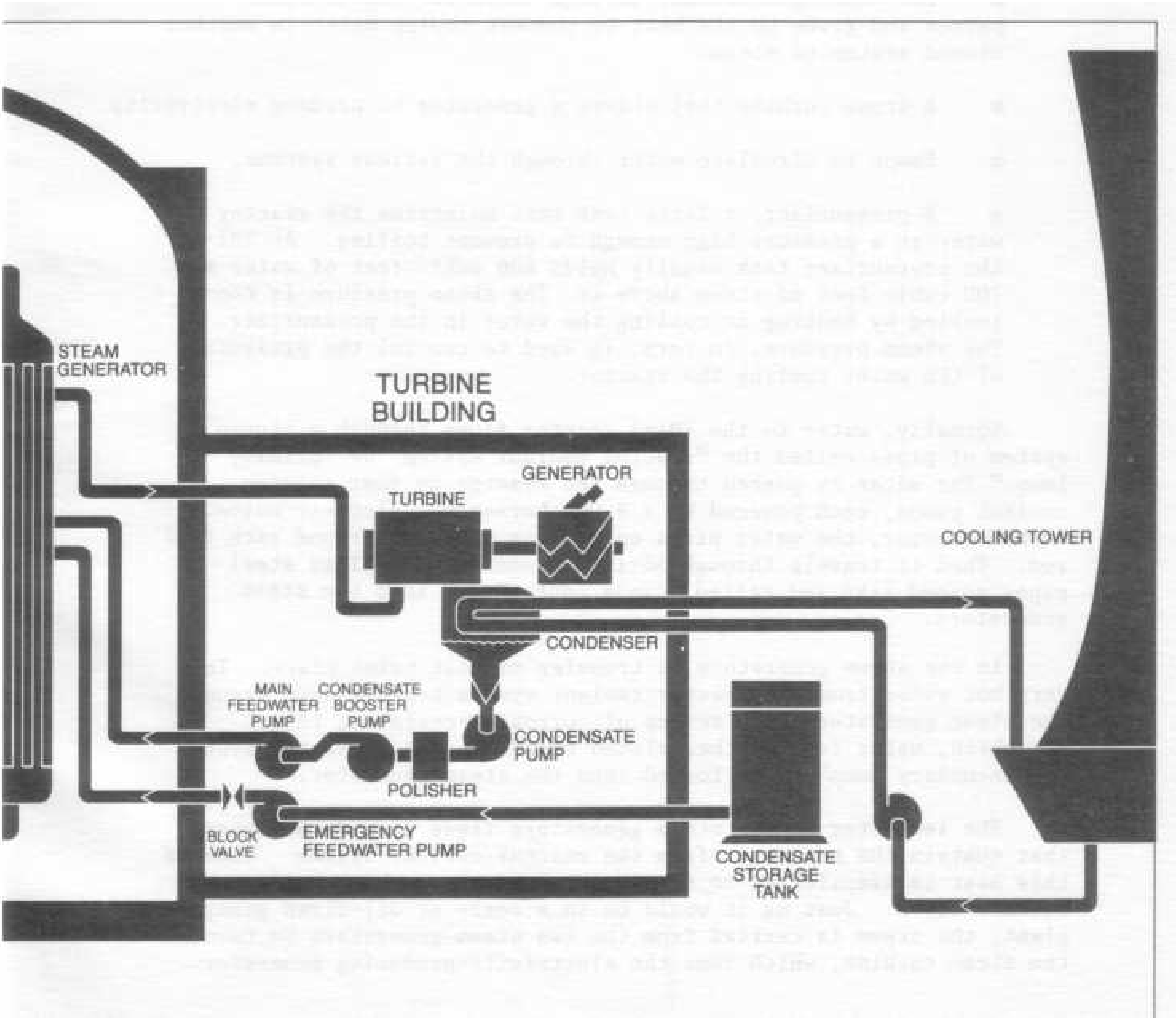
Schematic of the TMI-2 facility.



itself is not a danger, because it too can help cool the fuel rods, although not as effectively as the coolant water. But problems can occur if so much of the core's coolant water boils away that the core becomes uncovered.

An uncovered core may lead to two problems. First, temperature may rise to a point, roughly 2,200°F, where a reaction of water and the cladding could begin to damage the fuel rods and also produce hydrogen. The other is that the temperature might rise above the melting point of the uranium fuel, which is about 5,200°F. Either poses a potential danger. Damage to the zirconium cladding releases some radioactive materials trapped inside the fuel rods into the core's cooling water. A melting of the fuel itself could release far more radioactive materials. If a significant portion of the



fuel should melt, the molten fuel could melt through the reactor vessel itself and release large quantities of radioactive materials into the containment building. What might happen following such an event is very complicated and depends on a number of variables such as the specific characteristics of the materials on which a particular containment building is constructed.10/

The essential elements of the TMI-2 system during normal operations include:

- The reactor, with its fuel rods and control rods.
- Water, which is heated by the fission process going on inside the fuel rods to ultimately produce steam to run the turbine. This water, by removing heat, also keeps the fuel rods from becoming overheated.
- Two steam generators, through which the heated water passes and gives up its heat to convert cooler water in another closed system to steam.
- A steam turbine that drives a generator to produce electricity.
- Pumps to circulate water through the various systems.
- A pressurizer, a large tank that maintains the reactor water at a pressure high enough to prevent boiling. At TMI-2, the pressurizer tank usually holds 800 cubic feet of water and 700 cubic feet of steam above it. The steam pressure is controlled by heating or cooling the water in the pressurizer. The steam pressure, in turn, is used to control the pressure of the water cooling the reactor.

Normally, water to the TMI-2 reactor flows through a closed system of pipes called the "reactor coolant system" or "primary loop." The water is pushed through the reactor by four reactor coolant pumps, each powered by a 9,000 horsepower electric motor. In the reactor, the water picks up heat as it flows around each fuel rod. Then it travels through 36-inch diameter, stainless steel pipes shaped like and called "candy canes," and into the steam generators.

In the steam generators, a transfer of heat takes place. The very hot water from the reactor coolant system travels down through the steam generators in a series of corrosion-resistant tubes. Meanwhile, water from another closed system -- the feedwater system or "secondary loop" -- is forced into the steam generator.

The feedwater in the steam generators flows around the tubes that contain the hot water from the reactor coolant system. Some of this heat is transferred to the cooler feedwater, which boils and becomes steam. Just as it would be in a coal- or oil-fired generating plant, the steam is carried from the two steam generators to turn the steam turbine, which runs the electricity-producing generator.

The water from the reactor coolant system, which has now lost some of its heat, is pumped back to the reactor to pass around the fuel rods, pick up more heat, and begin its cycle again.

The water from the feedwater system, which has turned to steam to drive the turbine, passes through devices called condensers. Here, the steam is condensed back to water, and is forced back to the steam generators again.

The condenser water is cooled in the cooling towers. The water that cools the condensers is also in a closed system or loop. It cools the condensers, picks up heat, and is pumped to the cooling towers, where it cascades along a series of steps. As it does, it releases its heat to the outside air, creating the white vapor plumes that drift skyward from the towers. Then the water is pumped back to the condensers to begin its cooling process over again.

Neither the water that cools the condensers, nor the vapor plumes that rise from the cooling towers, nor any of the water that runs through the feedwater system is radioactive under normal conditions. The water that runs through the reactor coolant system is radioactive, of course, since it has been exposed to the radioactive materials in the core.

The turbine, the electric generator it powers, and most of the feedwater system piping are outside the containment building in other structures. The steam generators, however, which must be fed by water from both the reactor coolant and feedwater systems, are inside the containment building with the reactor and the pressurizer tank.

A nuclear power facility is designed with many ways to protect against system failure. Each of its major systems has an automatic backup system to replace it in the event of a failure. For example, in a loss-of-coolant accident (LOCA) -- that is, an accident in which there is a loss of the reactor's cooling water -- the Emergency Core Cooling System (ECCS) automatically uses existing plant equipment to ensure that cooling water covers the core.

In a LOCA, such as occurred at TMI-2, a vital part of the ECCS is the High Pressure Injection (HPI) pumps, which can pour about 1,000 gallons a minute into the core to replace cooling water being lost through a stuck-open valve, broken pipe, or other type of leak. But the ECCS can be effective only if plant operators allow it to keep running and functioning as designed. At Three Mile Island, they did not.

WEDNESDAY; MARCH 28

In the parlance of the electric power industry, a "trip" means a piece of machinery stops operating. A series of feedwater system pumps supplying water to TMI-2's steam generators tripped on the morning of March 28, 1979. The nuclear plant was operating at 97 percent power at the time. The first pump trip occurred at 36 seconds after 4:00 a.m. When the pumps stopped, the flow of water to the steam generators stopped. With no feedwater being added, there soon would be no steam, so the plant's safety system automatically shut down the steam turbine and the electric generator it powered. The incident at Three Mile Island was 2 seconds old.

The production of steam is a critical function of a nuclear reactor. Not only does steam run the generator to produce electricity but also, as steam is produced, it removes some of the intense heat that the reactor water carries.

When the feedwater flow stopped, the temperature of the reactor coolant increased. The rapidly heating water expanded. The pressurizer level (the level of the water inside the pressurizer tank) rose and the steam in the top of the tank compressed. Pressure inside the pressurizer built to 2,255 pounds per square inch, 100 psi more than normal. Then a valve atop the pressurizer, called a pilot-operated relief valve, or PORV, opened -- as it was designed to do -- and steam and water began flowing out of the reactor coolant system through a drain pipe to a tank on the floor of the containment building. 11/ Pressure continued to rise, however, and 8 seconds after the first pump tripped, TMI-2's reactor -- as it was designed to do -- scrammed: its control rods automatically dropped down into the reactor core to halt its nuclear fission.

Less than a second later, the heat generated by fission was essentially zero. But, as in any nuclear reactor, the decaying radioactive materials left from the fission process continued to heat the reactor's coolant water. This heat was a small fraction -- just 6 percent -- of that released during fission, but it was still substantial and had to be removed to keep the core from overheating. When the pumps that normally supply the steam generator with water shut down, three emergency feedwater pumps automatically started. Fourteen seconds into the accident, an operator in TMI-2's control room noted the emergency feed pumps were running. He did not notice two lights that told him a valve was closed on each of the two emergency feedwater lines and thus no water could reach the steam generators. One light was covered by a yellow maintenance tag. No one knows why the second light was missed.12/

With the reactor scrammed and the PORV open, pressure in the reactor coolant system fell. Up to this point, the reactor system was responding normally to a turbine trip. The PORV should have closed 13 seconds into the accident, when pressure dropped to 2,205 psi. It did not. A light on the control room panel indicated that the electric power that opened the PORV had gone off, leading the operators to assume the valve had shut. 13/ But the PORV was stuck open, and would remain open for 2 hours and 22 minutes, draining needed coolant water -- a LOCA was in progress. In the first 100 minutes of the accident, some 32,000 gallons -- over one-third of the entire capacity of the reactor coolant system -- would escape through the PORV and out the reactor's let-down system. Had the valve closed as it was designed to do, or if the control room operators had realized that the valve was stuck open and closed a backup valve to stem the flow of coolant water, or if they had simply left on the plant's high pressure injection pumps, the accident at Three Mile Island would have remained little more than a minor inconvenience for Met Ed.

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To a casual visitor, the control room at TMI-2 can be an intimidating place, with messages coming from the loudspeaker of the plant's paging system; panel upon panel of red, green, amber, and white lights; and alarms that sound or flash warnings many times each hour. Reactor operators are trained how to respond and to respond quickly in emergencies. Initial actions are ingrained, almost automatic and unthinking.14/

The burden of dealing with the early, crucial stages of the accident at Three Mile Island fell to four men -- William Zewe, shift supervisor in charge of both TMI-1 and TMI-2; Fred Scheimann, shift foreman for TMI-2; and two control room operators, Edward Frederick and Craig Faust. Each had been trained for his job by Met Ed and Babcock & Wilcox, the company that supplied TMI-2's reactor and nuclear steam system; each was licensed by the Nuclear Regulatory Commission; each was a product of his training -- training that did not adequately prepare them to cope with the accident at TMI-2. 15/ Indeed, their training was partly responsible for escalating what should have been a minor event into a potentially devastating accident.

Frederick and Faust were in the control room 16/ when the first alarm sounded, followed by a cascade of alarms that numbered 100 within minutes. The operators reacted quickly as trained to counter the turbine trip and reactor scram. Later Faust would recall for the Commission his reaction to the incessant alarms: "I would have liked to have thrown away the alarm panel. It wasn't giving us any

TMI-2 control room.

useful information."17/ Zewe, working in a small, glass-enclosed office behind the operators, alerted the TMI-1 control room of the TMI-2 scram and called his shift foreman back to the control room.

Scheimann had been overseeing maintenance on the plant's Number 7 polisher -- one of the machines that remove dissolved minerals from the feedwater system. His crew was using a mixture of air and water to break up resin that had clogged a resin transfer line. Later investigation would reveal that a faulty valve in one of the polishers allowed some water to leak into the air-controlled system that opens and closes the polishers' valves and may have been a factor in their sudden closure just before the accident began. This malfunction probably triggered the initial pump trip that led to the accident. The same problem of water leaking into the polishers' valve control system had occurred at least twice before at TMI-2. Had Met Ed corrected the earlier polisher problem, the March 28 sequence of events may never have begun.18/

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With the PORV stuck open and heat being removed by the steam generators, the pressure and temperature of the reactor coolant system dropped. The water level also fell in the pressurizer. Thirteen seconds into the accident, the operators turned on a pump to add water to the system. This was done because the water in the system was shrinking as it cooled. Thus more water was needed to fill the system. Forty-eight seconds into the incident, while pressure continued falling, the water level in the pressurizer began to rise again. The reason, at this point, was that the amount of water being pumped into the system was greater than that being lost through the PORV.

About a minute and 45 seconds into the incident, because their emergency water lines were blocked, the steam generators boiled dry. After the steam generators boiled dry, the reactor coolant heated up again, expanded, and this helped send the pressurizer level up further.

Two minutes into the incident, with the pressurizer level still rising, pressure in the reactor coolant system dropped sharply. Automatically, two large pumps began pouring about 1,000 gallons a minute into the system. The pumps, called high pressure injection (HPI) pumps, are part of the reactor's emergency core cooling system. The level of water in the pressurizer continued to rise, and the operators, conditioned to maintain a certain level in the pressurizer, took this to mean that the system had plenty of water in it.19/ However, the pressure of reactor coolant system water was falling, and its temperature became constant.

About 2-/ minutes after the HPI pumps began working, Frederick shut one down and reduced the flow of the second to less than 100 gallons per minute. The falling pressure, coupled with a constant reactor coolant temperature after HPI came on, should have clearly alerted the operators that TMI-2 had suffered a LOCA, and safety required they maintain high pressure injection. "The rapidly increasing pressurizer level at the onset of the accident led me to believe that the high pressure injection was excessive, and that we were soon going to have a solid system," Frederick later told the Commission.20/

A solid system is one in which the entire reactor and its cooling system, including the pressurizer, are filled with water. The operators had been taught to keep the system from "going solid" a condition that would make controlling the pressure within the reactor coolant system more difficult and that might damage the system. The operators followed this line of reasoning, oblivious for over 4 hours to a far greater threat -- that the loss of water from the system could result in uncovering the core.21/

The saturation point was reached 5-~ minutes into the accident. Steam bubbles began forming in the reactor coolant system, displacing the coolant water in the reactor itself. The displaced water moved into the pressurizer, sending its level still higher. This continued to suggest to the operators that there was plenty of water in the system. They did not realize that water was actually flashing into steam in the reactor, and with more water leaving the system than being added, the core was on its way to being uncovered. 22/ And so the operators began draining off the reactor's cooling water through piping called the let-down system.

Eight minutes into the accident, someone -- just who is a matter of dispute -- discovered that no emergency feedwater was reaching the steam generators. Operator Faust scanned the lights on the control panel that indicate whether the emergency feedwater valves are open or closed. He first checked a set of emergency feedwater valves designed to open after the pumps reach full speed; they were open. Next he checked a second pair of emergency feedwater valves, called the "twelve-valves," which are always supposed to be open, except during a specific test of the emergency feedwater pumps. The two "twelve-valves" were closed. Faust opened them and water rushed into the steam generators.23/

The two "twelve-valves" were known to have been closed 2 days earlier, on March 26, as part of a routine test of the emergency feedwater pumps. A Commission investigation has not identified a specific reason as to why the valves were closed at 8 minutes into the accident. The most likely explanations are: the valves were never reopened after the March 26 test; or the valves were reopened and the control room operators mistakenly closed the valves during the very first part of the accident; or the valves were closed mistakenly from control points outside the control room after the test. The loss of emergency feedwater for 8 minutes had no significant effect on the outcome of the accident. 24/ But it did add to the confusion that distracted the operators as they sought to understand the cause of their primary problem.

Throughout the first 2 hours of the accident, the operators ignored or failed to recognize the significance of several things that should have warned them that they had an open PORV and a loss-of-coolant accident. One was the high temperatures at the

TMI-2 control room operators testifying before the Commission.
Seated (1 to r) are Ernest Blake, legal counsel to Met Ed, and operators Fred Scheimann, William Zewe, Edward Frederick, and Craig Faust.

drain pipe that led from the PORV to the reactor coolant drain tank. One emergency procedure states that a pipe temperature of 200°F indicates an open PORV. Another states that when the drain pipe temperature reaches 130 °F, the block valve beneath it should be closed. 25/ But the operators testified that the pipe temperature normally registered high because either the PORV or some other valve was leaking slightly. "I have seen, in reviewing logs since the accident, approximately 198 degrees," Zewe told the Commission. "But I can remember instances before . . . just over 200 degrees."26/ So Zewe and his crew dismissed the significance of the temperature readings, which Zewe recalled as being in the 230 °F range. Recorded data show the range reached 285°F. Zewe told the Commission that he regarded the high temperatures on the drain pipe as residual heat: ". . .[K]nowing that the relief valve had lifted, the downstream temperature I would expect to be high and that it would take some time for the pipe to cool down below the 200-degree set point."27/

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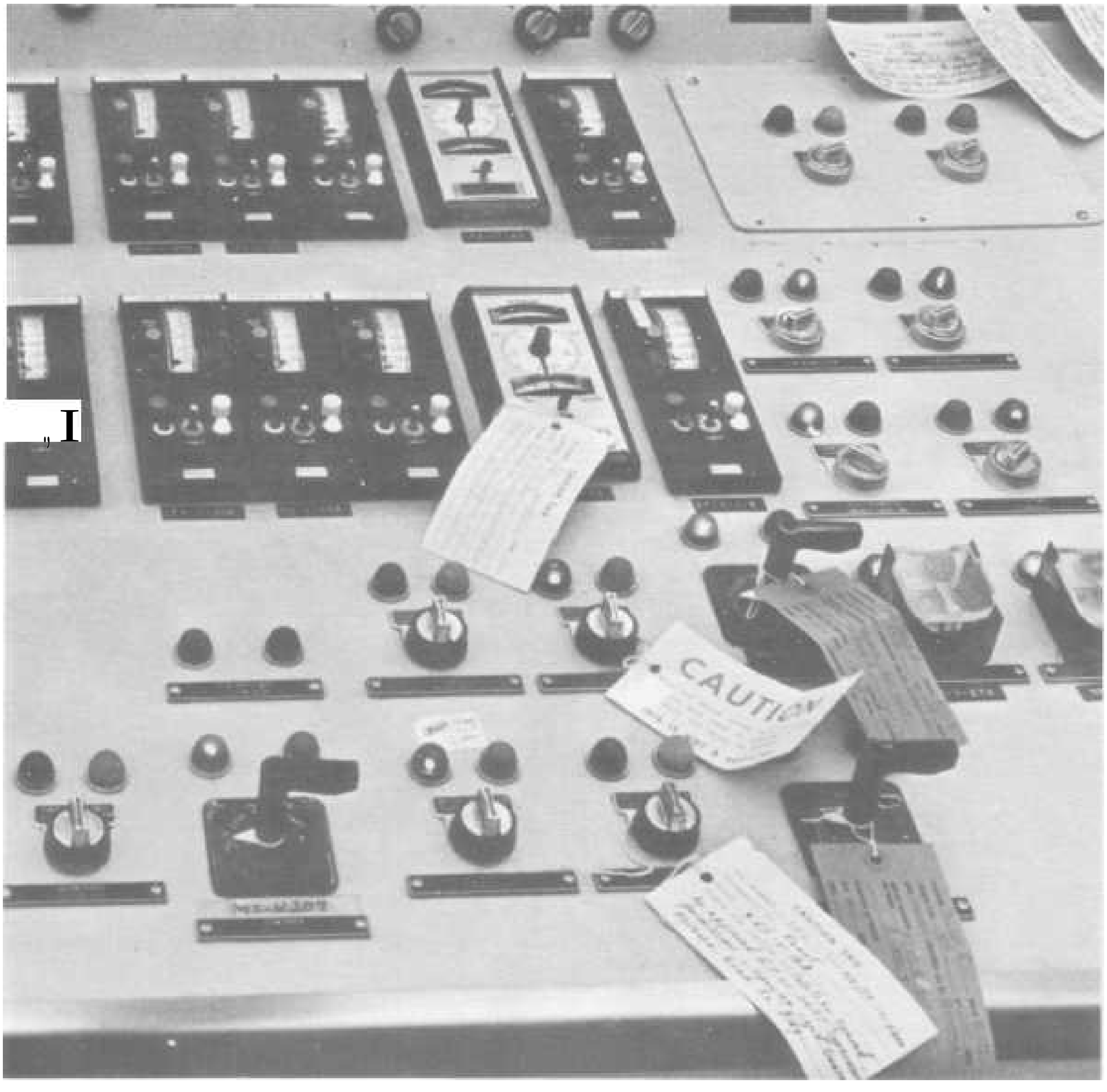
At 4:11 a.m., an alarm signaled high water in the containment building's sump, a clear indication of a leak or break in the system. The water, mixed with steam, had come from the open PORV, first falling to the drain tank on the containment building floor and finally filling the tank and flowing into the sump. At 4:15 a.m., a rupture disc on the drain tank burst as pressure in the tank rose. This sent more slightly radioactive water onto the floor and into the sump. From the sump it was pumped to a tank in the nearby auxiliary building.

Five minutes later, at 4:20 a.m., instruments measuring the neutrons inside the core showed a count higher than normal, another indication -- unrecognized by the operators -- that steam bubbles were present in the core and forcing cooling water away from the fuel rods. During this time, the temperature and pressure inside the containment building rose rapidly from the heat and steam escaping via the PORV and drain tank. The operators turned on the cooling equipment and fans inside the containment building. The fact that they failed to realize that these conditions resulted from a LOCA indicates a severe deficiency **in** their training to identify the symptoms of such an accident.28/

About this time, Edward Frederick took a call from the auxiliary building. He was told an instrument there indicated more than 6 feet of water in the containment building sump. Frederick queried the control room computer and got the same answer. Frederick recommended shutting off the two sump pumps in the containment building. He did not know where the water was coming from and did not want to pump water of unknown origin, which might be radioactive, outside the containment building.29/ Both sump pumps were stopped about 4:39 a.m. Before they were, however, as much as 8,000 gallons of slightly radioactive water may have been pumped into the auxiliary building.30/ Only 39 minutes had passed since the start of the accident.

Control panel of TMI-2, showing maintenance tags that operators testified covered one of the closed emergency feedwater valve indicator lights during the first 8 minutes of the accident.



Gary Miller (1), station manager of TMI, and George Kunder (r), TMI-2's superintendent for technical support, testifying before the Commission.

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George Kunder, superintendent of technical support at TMI-2, arrived at the Island about 4:45 a.m., summoned by telephone. Kunder was duty officer that day, and he had been told TMI-2 had had a turbine trip and reactor scram. What he found upon his arrival was not what he expected. "I felt we were experiencing a very unusual situation, because I had never seen pressurizer level go high and peg in the high range, and at the same time, pressure being low," he told the Commission. "They have always performed consistently."31/ Kunder's view was shared by the control room crew. They later described the accident as a combination of events they had never experienced, either in operating the plant or in their training simulations.32/

Shortly after 5:00 a.m., TMI-2's four reactor coolant pumps began vibrating severely. This resulted from pumping steam as well as water, and it was another indication that went unrecognized that the reactor's water was boiling into steam. The operators feared the violent shaking might damage the pumps -- which force water to circulate through the core -- or the coolant piping.33/

Zewe and his operators followed their training. At 5:14 a.m., two of the pumps were shut down. Twenty-seven minutes later, operators turned off the two remaining pumps, stopping the forced flow of cooling water through the core.

There was already evidence by approximately 6:00 a.m. that at least a few of the reactor's fuel rod claddings had ruptured from high gas pressures inside them, allowing some of the radioactive gases within the rods to escape into the coolant water. The early warning came from radiation alarms inside the containment building. With coolant continuing to stream out the open PORV and little water being added, the top of the core became uncovered and heated to the point where the zirconium alloy of the fuel rod cladding reacted with steam to produce hydrogen. Some of this hydrogen escaped into the containment building through the open PORV and drain tank; some of it remained within the reactor. This hydrogen, and possibly hydrogen produced later in the day, caused the explosion in the containment building on Wednesday afternoon and formed the gas bubble that produced such great concern a few days later.34/

Other TMI officials now were arriving in the TMI-2 control room. They included Richard Dubiel, a health physicist who served as supervisor of radiation protection and chemistry; Joseph Logan, superintendent of TMI-2; and Michael Ross, supervisor of operations for TMI-1.

Shortly after 6:00 a.m., George Kunder participated in a telephone conference call with John Herbein, Met Ed's vice president for generation; Gary Miller, TMI station manager and Met Ed's senior executive stationed at the nuclear facility; and Leland Rogers, the Babcock & Wilcox site representative at TMI. The four men discussed the situation at the plant. In his deposition, Rogers recalled a significant question he posed during that call: He asked if the block valve between the pressurizer and the PORV, a backup valve that could be closed if the PORV stuck open, had been shut.

> <u>QUESTION:</u> What was the response?
>
> <u>ROGERS:</u> George's immediate response was, "I don't know," and he had someone standing next to the shift supervisor over back of the control room and sent the guy to find out if the valve block was shut.
>
> <u>QUESTION:</u> You heard him give these instructions?
>
> <u>ROGERS:</u> Yes, and very shortly I heard the answer come back from the other person to George, and he said, "Yes, the block valve was shut. . . ."35/

The operators shut the block valve at 6:22 a.m., 2 hours and 22 minutes after the PORV had opened.

It remains, however, an open question whether Rogers or someone else was responsible for the valve being closed. Edward Frederick testified that the valve was closed at the suggestion of a shift supervisor coming onto the next shift; but Frederick has also testified that the valve was closed because he and his fellow operators could think of nothing else to do to bring the reactor back under control.36/

In any event, the loss of coolant was stopped, and pressure began to rise, but the damage continued. Evidence now indicates the water in the reactor was below the top of the core at 6:15 a.m. Yet for some unexplained reason, high pressure injection to replace the water lost through the PORV and let-down system was not initiated for almost another hour. Before that occurred, Kunder, Dubiel, and their colleagues would realize they faced a serious emergency at TMI-2.

In the 2 hours after the turbine trip, periodic alarms warned of low-level radiation within the unoccupied containment building. After 6:00 a.m., the radiation readings markedly increased. About 6:30 a.m., a radiation technician began surveying the TMI-2 auxiliary building, using a portable detector -- a task that took about 20 minutes. He reported rapidly increasing levels of radiation, up to one rem per hour. During this period, monitors in the containment and auxiliary buildings showed rising radiation levels. By 6:48 a.m., high radiation levels existed in several areas of the plant, and evidence indicates as much as two-thirds of the 12-foot high core stood uncovered at this time. Analyses and calculations made after the accident indicate temperatures as high as 3,500 to 4,000°F or more in parts of the core existed during its maximum uncovery. <u>37</u>/ At 6:54 a.m., the operators turned on one of the reactor coolant pumps, but shut it down 19 minutes later because of high vibrations. More radiation alarms went off. Shortly before 7:00 a.m., Kunder and Zewe declared a site emergency, required by TMI's emergency plan whenever some event threatens "an uncontrolled release of radioactivity to the immediate environment."38/

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Gary Miller, TMI station manager, arrived at the TMI-2 control room a few minutes after 7:00 a.m. Radiation levels were increasing throughout the plant. Miller had first learned of the turbine trip and reactor scram within minutes after they occurred. He had had several telephone conversations with people at the site, including the 6:00 a.m. conference call. When he reached Three Mile Island, Miller found that a site emergency existed. He immediately assumed command as emergency director and formed a team of senior employees to aid him in controlling the accident and in implementing TMI-2's emergency plan.39/

Miller told Michael Ross to supervise operator activities in the TMI-2 control room. Richard Dubiel directed radiation activities, including monitorings on- and off-site. Joseph Logan was charged with ensuring that all required procedures and plans were reviewed and followed. George Kunder took over technical support and communications. Daniel Shovlin, TMI's maintenance superintendent, directed emergency maintenance. B&W's Leland Rogers was asked to provide technical assistance and serve as liaison with his home office. Miller gave James Seelinger, superintendent of TMI-1, charge of the emergency control station set up in the TMI-1 control room. 40/ Under TMI's emergency plan, the control room of the unit not involved in an accident becomes the emergency control station. On March 28, TMI-1 was in the process of starting again after being shut down for refueling of its reactor.

TMI personnel were already following the emergency plan, telephoning state authorities about the site emergency. 41/ The Pennsylvania Emergency Management Agency (PEMA) was asked to notify the Bureau of Radiation Protection (BRP), part of Pennsylvania's Department of Environmental Resources. The bureau in turn telephoned Kevin Molloy, director of the Dauphin County Office of Emergency Preparedness. Dauphin County includes Harrisburg and Three Mile Island. Other nearby counties and the State Police were alerted.

Met Ed alerted the U.S. Department of Energy's Radiological Assistance Plan office at Brookhaven National Laboratory. But notifying the Nuclear Regulatory Commission's Region I office in King of Prussia, Pennsylvania, took longer. The initial phone call reached an answering service, which tried to telephone the NRC duty officer and the region's deputy director at their homes. Both were en route to work.

By the time the NRC learned of the accident -- when its Region I office opened at 7:45 a.m. -- Miller had escalated the site emergency at Three Mile Island to a general emergency. Shortly after 7:15 a.m., emergency workers had to evacuate the TMI-2 auxiliary building. William Dornsife, a nuclear engineer with the Pennsylvania Bureau of Radiation Protection, was on the telephone to the TMI-2 control room at the time. He heard the evacuation ordered over the plant's paging system. "And I said to myself, 'This is the biggie,'" Dornsife recalled in his deposition.42/

At 7:20 a.m., an alarm indicated that the radiation dome monitor high in the containment building was reading 8 rems per hour. The monitor is shielded by lead. This shielding is designed to cut the radioactivity reaching the monitor by 100 times. Thus, those in the control room interpreted the monitor's alarm as meaning that the radiation present in the containment building at the time was about 800 rems per hour. Almost simultaneously, the operators finally turned on the high pressure injection pumps, once again dumping water into the reactor, but this intense flow was kept on for only 18 minutes. Other radiation alarms sounded in the control room. Gary Miller declared a general emergency at 7:24 a.m. By definition, at Three Mile Island, a general emergency is an "incident which has the potential for serious radiological consequences to the health and safety of the general public."43/

As part of TMI's emergency plan, state authorities were again notified and teams were sent to monitor radiation on the Island and ashore. The first team, designated Alpha and consisting of two radiation technicians, was sent to the west side of the Island, the downwind direction at the time. Another two-man team, designated Charlie, left for Goldsboro, a community of some 600 persons on the west bank of the Susquehanna River across from Three Mile Island. Meanwhile, a team sent into the auxiliary building reported increasing radiation levels and the building's basement partly flooded with water. At 7:48 a.m., radiation team Alpha reported radiation levels along the Island's west shoreline were less than one millirem per hour. Minutes later, another radiation team reported similar readings at the Island's north gate and along Route 441, which runs parallel to the Susquehanna's eastern shore.

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Nearly 4 hours after the accident began, the containment building automatically isolated. Isolation is intended to help prevent radioactive material released by an accident from escaping into the environment. The building is not totally closed off. Pipes carrying coolant run between the containment and auxiliary buildings. These pipes close off when the containment building isolates, but the operators can open them. This occurred at TMI-2 and radioactive water flowed through these pipes even during isolation. Some of this piping leaked radioactive material into the auxiliary building, some of which escaped from there into the atmosphere outside.44/

In September 1975, the NRC instituted its Standard Review Plan, which included new criteria for isolation. The plan listed three conditions -- increased pressure, rising radiation levels, and emergency core cooling system activation -- and required that containment buildings isolate on any two of the three. However, the plan was not applied to nuclear plants that had already received their construction permits. TMI-2 had, so it was "grandfathered" and not required to meet the Standard Review Plan, although the plant had yet to receive its operating license.45/

In the TMI-2 design, isolation occurred only when increasing pressure in the containment building reached a certain point, nominally 4 pounds per square inch. Radiation releases alone, no matter how intense, would not initiate isolation, nor would ECCS activation.46/

Although large amounts of steam entered the containment building early in the TMI-2 accident through the open PORV, the operators had kept pressure there low by using the building's cooling and ventilation system. But the failure to isolate early made little difference in the TMI-2 accident. Some of the radioactivity ultimately released into the atmosphere occurred after isolation from leaks in the let-down system that continued to carry radioactive water out of the containment building into the auxiliary building.47/

At 8:26 a.m., the operators once again turned on the ECCS's high pressure injection pumps and maintained a relatively high rate of flow. The core was still uncovered at this time and evidence indicates it took until about 10:30 a.m. for the HPI pumps to fully cover the core again.

By 7:50 a.m., NRC Region I officials had established direct telephone contact with the TMI-2 control room. Ten minutes later, Region I activated its Incident Response Center at King of Prussia, opened a direct telephone line to the Emergency Control Station in the TMI-1 control room, and notified NRC staff headquarters in Bethesda, Maryland. Region I officials gathered what information they could and relayed it to NRC headquarters, which had activated its own Incident Response Center. Region I dispatched two teams of inspectors to Three Mile Island; the first left at about 8:45 a.m., the second a few minutes later.

Around 8:00 a.m., it was clear to Gary Miller that the TMI-2 reactor had suffered some fuel damage. The radiation levels told him that. Yet Miller would testify to the Commission: ". . . I don't believe in my mind I really believed the core had been totally uncovered, or uncovered to a substantial degree at that time."48/

Off the Island, radiation readings continued to be encouragingly low. Survey team Charlie reported no detectable radiation in Goldsboro. Miller and several aides concluded about 8:30 a.m. that the emergency plan was being properly implemented.

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WKBO, a Harrisburg "Top 40" music station, broke the story of TMI-2 on its 8:25 a.m. newscast. The station's traffic reporter, known as Captain Dave, uses an automobile equipped with a CB radio to gather his information. About 8:00 a.m. he heard police and fire fighters were mobilizing in Middletown and relayed this to his station. Mike Pintek, WKBO's news director, called Three Mile Island and asked for a public relations official. He was connected instead with the control room to a man who told him: "I can't talk now, we've got a problem." The man denied that "there are any fire engines," and told Pintek to telephone Met Ed's headquarters in Reading, Pennsylvania.

Pintek did, and finally reached Blaine Fabian, the company's manager of communications services. In an interview with the Commission staff, Pintek told what happened next:

> Fabian came on and said there was a general emergency. What the hell is that? He said that general emergency was a "red-tape" type of thing required by the NRC when certain conditions exist. What conditions? "There was a problem with a feedwater pump. The plant is shut down. We're working on it. There's no danger off-site. No danger to the general public." And that is the story we went with at 8:25. I tried to tone it down so people wouldn't be alarmed.49/

At 9:06 a.m., the Associated Press filed its first story -- a brief dispatch teletyped to newspaper, television, and radio news rooms across the nation. The article quoted Pennsylvania State Police as saying a general emergency had been declared, "there is no radiation leak," and that Met Ed officials had requested a State Police helicopter "that will carry a monitoring team." The story contained only six sentences in four paragraphs, but it alerted editors to what would become one of the most heavily reported news stories of 1979.50/

Many public officials learned of the accident from the news media, rather than from the state, or their own emergency preparedness people. Harrisburg Mayor Paul Doutrich was one, and that still rankled him when he testified before the Commission 7 weeks later. Doutrich heard about the problem in a 9:15 a.m. telephone call from a radio station in Boston. "They asked me what we were doing about the nuclear emergency," Doutrich recalled. "My response was, 'What nuclear emergency?' They said, 'Well, at Three Mile Island.' I said, 'I know nothing about it. We have a nuclear plant there, but I know nothing about a problem.' So they told me; a Boston radio station."51/

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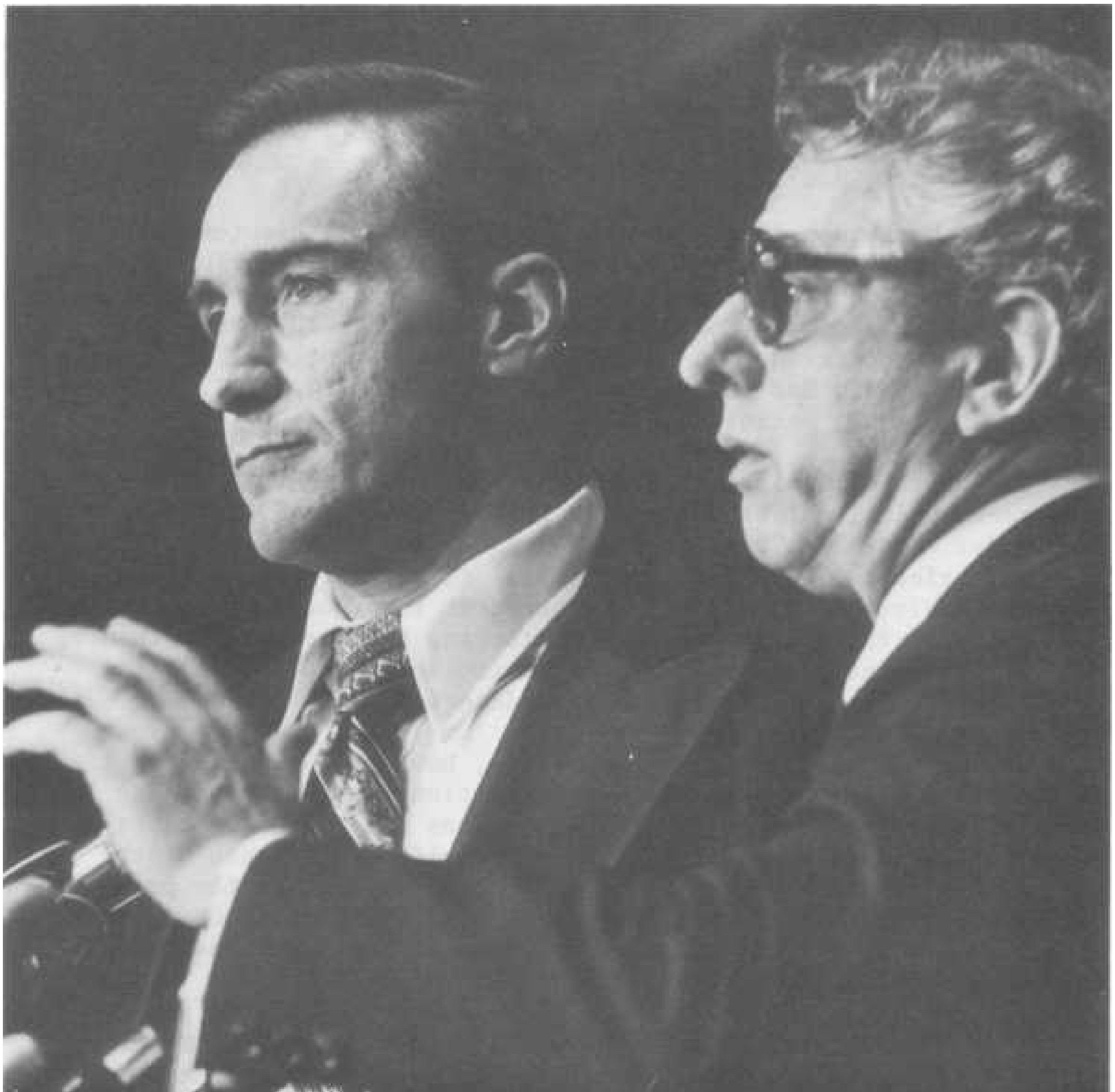
At 9:15 a.m., the NRC notified the White House of the events at Three Mile Island. Seven minutes later, an air sample taken in Goldsboro detected low levels of radioactive iodine-131. This specific reading was erroneous; a later, more sensitive analysis of the sample found no iodine-131. At 9:30 a.m., John Herbein, Met Ed's vice president for generation, was ordered to Three Mile Island from Philadelphia by Met Ed President Walter Creitz. And at 10:05 a.m., the first contingent of NRC Region I officials arrived at Three Mile Island.

In the days to follow, the NRC would dominate the public's perception of the events at Three Mile Island. But the initial NRC team consisted of only five Region I inspectors, headed by Charles Gallina. The five were briefed in the TMI-1 control room on the status of TMI-2. Then Gallina sent two inspectors into the TMI-2 control room and two more out to take radiation measurements; he himself remained in the TMI-1 control room to coordinate their reports and relay information to both Region I and NRC headquarters.52/

While the NRC team received its briefing, monitors indicated that radiation levels in the TMI-2 control room had risen above the levels considered acceptable in NRC regulations. Workers put on

John Herbein (1), Met Ed vice president for generation, and
Walter Creitz (r), Met Ed president, at a March 29 press conference.



protective face masks with filters to screen out any airborne radioactive particles. This made communications among those managing the accident difficult. At 11:00 a.m., all nonessential personnel were ordered off the Island. At the same hour, both Pennsylvania's Bureau of Radiation Protection and the NRC requested the Department of Energy to send a team from Brookhaven National Laboratory to assist in monitoring environmental radiation.53/

About this time, Mayor Robert Reid of Middletown telephoned Met Ed's home office in Reading. He was assured, he later told the Commission, that no radioactive particles had escaped and no one was injured.

> I felt relieved and relaxed; I said, "There's no problem." Twenty seconds later I walked out of my office and got in my car and turned the radio on and the announcer told me, over the radio, that there were radioactive particles released. Now, I said, "Gee whiz, what's going on here?" At 4:00 in the afternoon the same day the same man called me at home and said, "Mayor Reid, I want to update our conversation that we had at 11:00 a.m." I said, "Are you going to tell me that [radioactive] particles were released?" He said, "Yes." I said, "I knew that 20 seconds after I spoke to you on the phone."54/

Throughout much of the morning, Pennsylvania's Lieutenant Governor William Scranton, III, focused his attention on Three Mile Island. Scranton was charged, among other things, with overseeing the state's emergency preparedness functions. He had planned a morning press conference on energy conservation, but when he finally faced reporters in Harrisburg, the subject was TMI-2. 55/ In a brief opening statement, Scranton said:

> The Metropolitan Edison Company has informed us that there has been an incident at Three Mile Island, Unit-2. Everything is under control. There is and was no danger to public health and safety. . . . There was a small release of radiation to the environment. All safety equipment functioned properly. Metropolitan Edison has been monitoring the air in the vicinity of the plant constantly since the incident. No increase in normal radiation levels has been detected 56/

During the questioning by reporters, however, William Dornsife of the state's Bureau of Radiation Protection, who was there at Scranton's invitation, said Met Ed employees had "detected a small amount of radioactive iodine. . . ." Dornsife had learned of the iodine reading (later found to be in error) just before the press conference began and had not had time to tell Scranton. Dornsife dismissed any threat to human health from the amount of radioactive iodine reported in Goldsboro.57/

Shortly after the press conference, a reporter told Scranton that Met Ed in Reading denied any off-site radiation. While some company executives were acknowledging radiation readings off the Island, low-level public relations officials at Met Ed's headquarters continued until noon to deny any off-site releases. It was an error in communications within Met Ed, one of several that would reduce the utility's credibility with public officials and the press. "This was the first contradictory bit of information that we received and it caused some disturbance," Scranton told the Commission in his testimony-58/

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At Three Mile Island, the control room was crowded with operators and supervisors trying to bring the plant under control. They had failed in efforts to establish natural circulation cooling. This essentially means setting up a flow of water, without mechanical assistance, by heating water in the core and cooling it in the steam generators. This effort failed because the reactor coolant system was not filled with water and a gas bubble forming in the top of the reactor blocked this flow of water. At 11:38 a.m., operators began to decrease pressure in the reactor system. The pressurizer block valve was opened and high pressure injection cut sharply. This resulted again in a loss of coolant and an uncovering of the core. The depressurization attempt ended at 3:08 p.m.59/ The amount and duration of core uncovery during this period remains unknown.

About noon, three employees entered the auxiliary building and found radiation levels ranging from 50 millirems to 1,000 rems (one million millirems) an hour. Each of the three workers received an 800-millirem dose during the entry. 60/ At 12:45 p.m., the Pennsylvania State Police closed Route 441 to traffic near Three Mile Island at the request of the state's Bureau of Radiation Protection. An hour later, the U.S. Department of Energy team began its first helicopter flight to monitor radiation levels. And at 1:50 p.m., a noise penetrated the TMI-2 control room; "a thud," as Gary Miller later characterized it.61/

That thud was the sound of a hydrogen explosion inside the containment building. It was heard in the control room; its force of 28 pounds per square inch was recorded on a computer strip chart there, which Met Ed's Michael Ross examined within a minute or two.62/ Yet Ross and others failed to realize the significance of the event. Not until late Thursday was that sudden and brief rise in pressure recognized as an explosion of hydrogen gas released from the reactor. The noise, said B&W's Leland Rogers in his deposition, was dismissed at the time as the slamming of a ventilation damper. 63/ And the pressure spike on the strip chart, Ross explained to the Commission, "we kind of wrote it off . . . [as] possibly instrument malfunction. . . ."64/

Miller, Herbein, and Kunder left for Harrisburg soon afterwards for a 2:30 p.m. briefing with Lieutenant Governor Scranton on the events at Three Mile Island. At 2:27 p.m., radiation readings in Middletown ranged from 1 to 2 millirems per hour.65/

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The influx of news media from outside the Harrisburg area began during the afternoon. The wire service reports of Associated Press

TMI-2 control room several days after the start of the accident. The man in the foreground wearing a helmet is Charles Gallina, NRC inspector from Region I. The two men above Gallina are Craig Faust and William Zewe, both of whom were on duty when the accident began.

and United Press International had alerted editors here and abroad to the accident. The heavy flow of newspaper and magazine reporters, television and radio correspondents, and photographers and camera crews would come later as the sense of concern about Three Mile Island grew. But at 4:30 p.m., when Scranton once more met the press, he found some strange faces among the familiar crew of correspondents who regularly covered Pennsylvania's Capitol.

Scranton had discussed the TMI situation with his own people and listened to Met Ed officials. "I wouldn't say that they [Met Ed] were exactly helpful, but they were not obstructive," he later testified. "I think they were defensive." Scranton was disturbed by, among other things, Herbein's comment during their 2:30 p.m. meeting that Herbein had not told reporters about some radiation releases during an earlier Met Ed press conference because "it didn't come up."66/ So Scranton was less assured about conditions at Three Mile Island when he issued his afternoon statement to the press:

> This situation is more complex than the company first led us to believe. We are taking more tests. And at this point, we believe there is still no danger to public health. Metropolitan Edison has given you and us conflicting information. We just concluded a meeting with company officials and hope this briefing will clear up most of your questions. There has been a release of radioactivity into the environment. The magnitude of the release is still being determined, but there is no evidence yet that it has resulted in the presence of dangerous levels. The company has informed us that from 11:00 a.m. until about 1:30 p.m., Three Mile Island discharged into the air, steam that contained detectable amounts of radiation. . . .67/

Scranton's statement inappropriately focused public attention on the steam emissions from TMI-2 as a source of radiation. In fact, they were not, since the water that flows inside the towers is in a closed loop and cannot mix with water containing radioactive materials unless there is a leak in the system.

Scranton went on to discuss potential health effects of the radiation releases:

> The levels that were detected were below any existing or proposed emergency action levels. But we are concerned because any increased exposure carries with it some increased health risks. The full impact on public health is being evaluated as environmental samples are analyzed. We are concerned most about radioactive iodine, which can accumulate in the thyroid, either through breathing or through drinking milk. Fortunately, we don't believe the risk is significant because most dairy cows are on stored feed at this time of year.68/

Many Americans learned about the accident at Three Mile Island from the evening newscasts of the television networks. Millions, Lieutenant Governor William Scranton (1) and Oran Henderson (r), director of the Pennsylvania Emergency Management Agency, at a March 28 press conference.

for example, watched as Walter Cronkite led off the CBS Evening News:

> It was the first step in a nuclear nightmare; as far as we know at this hour, no worse than that. But a government official said that a breakdown in an atomic power plant in Pennsylvania today is probably the worst nuclear accident to date. . . .

At 7:30 p.m., Mayor Ken Myers of Goldsboro met with the borough council to discuss the accident and the borough's evacuation plan. Then Myers suggested he and the council members go door-to-door to talk with residents of the small community.

> Everyone listened to what we had to say. We mainly told them of what we had heard through the radio, TV, and even our own public relations and communications department in the basement of the York County court house. . . . Then we told them also of our evacuation plans in case the Governor would declare an emergency and that we would all have to leave. Of course, right away they gave us questions: "Well, what should we do? Do you think it's safe that we should stay or do you think we should go?" The ones that I talked to, I told them: "Use your own judgment. We dare not tell you to leave your homes."69/

THURSDAY, MARCH 29

In retrospect, Thursday seemed a day of calm. A sense of betterment, if not well-being, was the spirit for much of the day. Radiation levels remained high at points within the auxiliary building, but off-site readings indicated no problems. The log book kept by the Dauphin County Office of Emergency Preparedness reflects this mood of a crisis passing:

5:45 a.m.	Called Pennsylvania Emergency Management Agency Blaisdale, reactor remains under control more stable than yesterday, not back to normal, monitoring continues by Met Ed, Radiological Health, and Nuclear Regulatory Commission.
7:55 a.m.	Pennsylvania Emergency Management Agency -- . . . no danger to public.
11:25 a.m.	Pennsylvania Emergency Management Agency advised situation same.
3:30 p.m.	. . situation is improving.
6:12 p.m.	. . . no change -- not cold yet, continues to improve, slow rate, off-site release controlled.
7:00-9:00 p.m.	. . . Pennsylvania Emergency Management says Island getting better.
9:55 p.m.	. . . no real measureable reading off-site -- no health risk off-site, no emergency, bringing reactor to cold shut down. . . .70/

Radiation monitoring continued. Midmorning readings showed 5 to 10 millirems an hour on-site and 1 to 3 millirems per hour across the Susquehanna River to the west. No radioactive iodine was detected in the air. The U.S. Food and Drug Administration began monitoring food, milk, and water in the area for radiation contamination.71/

Sen. Gary Hart (l), Sen. Alan Simpson (c), and Rep. Allen Ertel (r) arrive at TMI for a briefing on the accident, March 29.

Thursday was a day of questioning. NRC Chairman Joseph Hendrie and several key aides journeyed to Capitol Hill to brief the House Subcommittee on Energy and the Environment and other members of Congress on the accident. Lieutenant Governor Scranton spent several hours in the early afternoon at Three Mile Island, touring the TMI-2 control room and auxiliary building, wearing a radiation suit and respirator during part of his inspection. That same afternoon, Met Ed officials and NRC inspectors briefed several visiting members of Congress, including Rep. Allen Ertel (D-Pa.), whose district includes Three Mile Island, and Sen. John Heinz (R-Pa.). Later in the day, a second Congressional delegation that included Sen. Richard Schweiker (R-Pa.) and Rep. William Goodling (R-Pa.), whose district includes York, Adams, and Cumberland counties, received a briefing.

Thursday was also a day of disquieting discussions and discoveries. Thursday afternoon, a telephone conversation took place between two old acquaintances, Gordon MacLeod, Pennsylvania's Secretary of Health, and Anthony Robbins, director of the National Institute for Occupational Safety and Health. One important point of that conversation remains in dispute. MacLeod recalls that Robbins urged him to recommend an evacuation of people living around Three Mile Island. 72/ Robbins denies discussing or suggesting such an evacuation.73

Up to this point, MacLeod -- who had taken office only 12 days before the accident -- had offered no recommendations since his department had no direct responsibility for radiological health matters. Now, however, he arranged a conference telephone call with Oran Henderson, director of the Pennsylvania Emergency Management Agency; Thomas Gerusky, director of the Bureau of Radiation Protection; and John Pierce, an aide to Lieutenant Governor Scranton. MacLeod told them Robbins had strongly recommended evacuation. The others rejected the idea, although they agreed it should be reconsidered if conditions proved worse than they appeared at TMI-2. MacLeod then asked if it might be wise to have pregnant women and children under age 2 leave the area around the nuclear plant. This, too, was rejected Thursday afternoon.74/

At 2:10 p.m., a helicopter over TMI-2 detected a brief burst of radiation that measured 3,000 millirems per hour 15 feet above the plant's vent. This information was relayed to NRC headquarters, where it created no great concern.

But another release that afternoon, one within NRC limits for radiation releases, did cause considerable consternation. Soon after the accident began Wednesday, Met Ed stopped discharging wastewater from such sources as toilets, showers, laundry facilities, and leakage in the turbine and control and service buildings into the Susquehanna River. Normally, this water contains little or no radioactivity, but as a result of the accident, some radioactive gases had contaminated it. The radiation levels, however, were within the limits set by the NRC. By Thursday afternoon, nearly 400,000 gallons of this slightly radioactive water had accumulated and the tanks were now close to overflowing. Two NRC officials -- Charles Gallina on-site and George Smith at the Region I office --

told Met Ed they had no objections to releasing the water so long as it was within NRC specifications. Met Ed notified the Bureau of Radiation Protection and began dumping the wastewater. No communities downstream from the plant were informed, nor was the press.75/

When NRC Chairman Hendrie learned of the release, he ordered it stopped. Hendrie did not know the water's source, and he was concerned about the impact on the public of the release of any radiation, no matter how slight. 76/ Some 40,000 gallons had entered the river when the dumping ceased around 6:00 p.m. Both NRC officials on-site and the Governor's aides realized that authorizing release of the wastewater would be unpopular, and neither was eager to do so. Yet the tanks still were close to overflowing. After hours of discussion, agreement was reached on the wording of a press release that the state's Department of Environmental Resources issued, which said DER "reluctantly agrees that the action must be taken." Release of the wastewater resumed shortly after midnight.77/

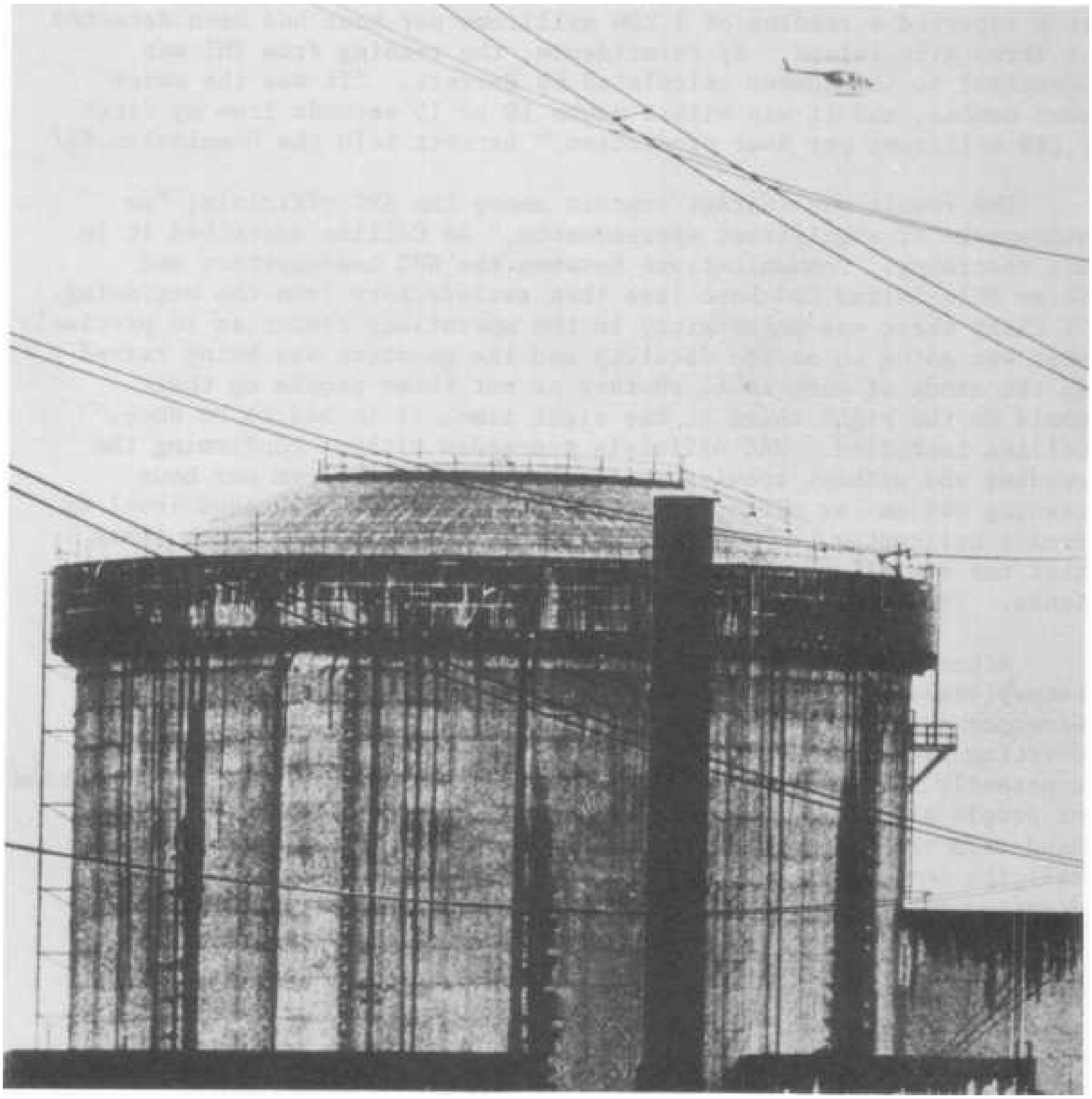
Late Thursday afternoon, Governor Thornburgh had held a press conference. At it, the NRC's Charles Gallina told reporters the danger was over for people off the Island. Thornburgh distrusted the statement at the time, and events soon confirmed his suspicion. At 6:30 p.m., Gallina and James Higgins, an NRC reactor inspector, received the results of an analysis of the reactor's coolant water. It showed that core damage was far more substantial than either had anticipated. At 10:00 p.m., Higgins telephoned the Governor's office with the new information and indicated that a greater possibility of radiation releases existed. Nothing had changed inside the plant, only NRC's awareness of the seriousness of the damage. Yet Higgins' call foretold events only hours away.78/

ERIDAY, MARCH 30

The TMI-2 reactor has a means of removing water from the reactor coolant system, called the let-down system, and one for adding water, called the make-up system. Piping from both runs through the TMI-2 auxiliary building, and NRC officials suspected that leaks in these two systems explained the sporadic, uncontrolled releases of radioactivity. They were also concerned about levels in the make-up tank and the two waste gas decay tanks inside the auxiliary building Water from the let-down system flows into the make-up tank. In that tank, gases dissolved in the reactor's cooling water at high pressure are released because the tank's pressure is lower, much as the gas bubbles in a pressurized carbonated beverage appear when the bottle is opened. These gases, under normal circumstances, are compressed and stored in the waste gas decay tanks. NRC officials worried that if the waste gas decay tanks filled to capacity, relief valves would open, allowing a continuing escape of radiation into the environment.79/ That concern and what Commission Chairman Kemeny would later call a "horrible coincidence" 80/ resulted in a morning of confusion, contradictory evacuation recommendations, and eventually an evacuation advisory from Governor Richard Thornburgh.

About halfway through his midnight-to-noon shift on Friday, James Floyd, TMI-2's supervisor of operations, decided to transfer radioactive gases from the make-up tank to a waste gas decay tank. Floyd knew this would release radiation because of leaks in the system, but he considered the transfer necessary. The pressure in the make-up tank was so high that water that normally flowed into it for transfer to the reactor coolant system could not enter the tank. Floyd, without checking with other TMI and Met Ed officials, ordered the transfer to begin at 7:10 a.m. to reduce the tank's pressure. This controlled release allowed radioactive material to escape into the auxiliary building and then into the air outside. Thirty-four minutes later, Floyd requested a helicopter be sent to take radiation measurements. The chopper reported readings of 1,000 millirems per hour at 7:56 a.m. and 1,200 millirems per hour at 8:01 a.m., 130 feet above the TMI-2 vent stack.81/

A helicopter taking air samples over the containment building.



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At NRC headquarters, Lake Barrett, a section leader in the environmental evaluation branch, was concerned about the waste gas decay tank level. The previous evening, he had helped calculate "a hypothetical release rate" for the radiation that would escape if the tank's relief valves opened. Shortly before 9:00 a.m., Barrett was told of a report from Three Mile Island that the waste gas decay tanks had filled. He was asked to brief senior NRC staff officials on the significance of this. The group included Lee Gossick, executive director for operations; John Davis, then acting director of Inspection and Enforcement; Harold Denton, director of Nuclear Reactor Regulation; Victor Stello, Jr., then director of the Office of Operating Reactors; and Harold Collins, assistant director for emergency preparedness in the Office of State Programs. During the briefing, Barrett was asked what the release rate would mean in terms of an off-site dose. He did a quick calculation and came up with a figure: 1,200 millirems per hour at ground level. Almost at that moment, someone in the room reported a reading of 1,200 millirems per hour had been detected at Three Mile Island. By coincidence, the reading from TMI was identical to the number calculated by Barrett. "It was the exact same number, and it was within maybe 10 or 15 seconds from my first 1,200 millirems per hour prediction," Barrett told the Commission.82/

The result was instant concern among the NRC officials; "an atmosphere of significant apprehension," as Collins described it in his testimony. Communications between the NRC headquarters and Three Mile Island had been less than satisfactory from the beginning. "I think there was uncertainty in the operations center as to precisely what was going on at the facility and the question was being raised in the minds of many as to whether or not those people up there would do the right thing at the right time, if it had to be done," Collins testified. NRC officials proceeded without confirming the reading and without knowing whether the 1,200 millirem per hour reading was on- or off-site, whether it was taken at ground level or from a helicopter, or what its source was. They would later learn that the radiation released did not come from the waste gas decay tanks. The report that these tanks had filled was in error.83/

After some discussion, Harold Denton directed Collins to notify Pennsylvania authorities that senior NRC officials recommended the Governor order an evacuation. Collins telephoned Oran Henderson, director of the Pennsylvania Emergency Management Agency, and, apparently selecting the distance on his own, recommended an evacuation of people as far as 10 miles downwind from Three Mile Island. Henderson telephoned Lieutenant Governor Scranton, who promised to call the Governor. A Henderson aide also notified Thomas Gerusky, director of the Bureau of Radiation Protection, of the evacuation recommendation. Gerusky knew of the 1,200 millirem reading. A telephone call to an NRC official at the plant reinforced Gerusky's belief that an evacuation was unnecessary. He tried to telephone Governor Thornburgh, found the lines busy, and went to the Governor's office to argue personally against an evacuation.84/

Kevin Molloy, director of emergency preparedness for Dauphin County, had received a call from Met Ed's James Floyd at 8:34 a.m., alerting him to the radiation release. Twenty minutes later, the Pennsylvania Emergency Management Agency notified Molloy of an on-site emergency and an increase in radiation, but Molloy was told that no evacuation was needed. Then at 9:25 a.m., Henderson called Molloy and told him to expect an official evacuation order in 5 minutes; the emergency preparedness offices in York and Lancaster counties received similar alerts. Molloy began his preparations. He notified all fire departments within 10 miles of the stricken plant, and broadcast a warning over radio station WHP that an evacuation might be called.85/

At Three Mile Island, NRC's Charles Gallina was confronted by a visibly upset Met Ed employee shortly after Molloy's broadcast. "As the best I can remember, he said, 'What the hell are you fellows doing? My wife just heard the NRC recommended evacuation,"' Gallina told the Commission. Gallina checked radiation readings on- and off-site and talked with an NRC reactor inspector, who said "things were getting better." Then Gallina telephoned NRC officials at Region I and at Bethesda headquarters in an attempt "to call back that evacuation notice."86/

Shortly after 10:00 a.m., Governor Thornburgh talked by telephone with Joseph Hendrie. The NRC chairman assured the Governor that no evacuation was needed. Still, Hendrie had a suggestion: that Thornburgh urge everyone within 5 miles downwind of the plant to stay indoors for the next half-hour. The Governor agreed and later that morning issued an advisory that all persons within 10 miles of the plant stay inside. During this conversation, Thornburgh asked Hendrie to send a single expert to Three Mile Island upon whom the Governor could rely for technical information and advice.87/

About an hour later, Thornburgh received a telephone call from President Carter, who had just talked with Hendrie. The President said that he would send the expert the Governor wanted. That expert would be Harold Denton. The President also promised that a special communications system would be set up to link Three Mile Island, the Governor's office, the White House, and the NRC.88/

Thornburgh convened a meeting of key aides to discuss conditions at Three Mile Island. During this meeting, at about 11:40 a.m., Hendrie again called the Governor. As Gerusky recalls the conversation that took place over a speaker phone, the NRC chairman apologized for the NRC staff error in recommending evacuation. Just before the call, Emmett Welch, an aide to Gordon MacLeod, had renewed the Secretary of Health's recommendation that pregnant women and children under age 2 be evacuated. Thornburgh told Hendrie of this. Gerusky recalls this response from Hendrie: "If my wife were pregnant and I had small children in the area, I would get them out because we don't know what is going to happen." 89/ After the call, Thornburgh decided to recommend that pregnant women and preschool children leave the region within a 5-mile radius of Three Mile Island and to close all schools within that area. He issued his advisory shortly after 12:30 p.m.

Thornburgh was conscious throughout the accident that an evacuation might be necessary, and this weighed upon him. He later shared some of his concerns in testimony before the Commission:

> There are known risks, I was told, in an evacuation. The movement of elderly persons, people in intensive care units, babies in incubators, the simple traffic on the highways that results from even the best of an orderly evacuation, are going to exert a toll in lives and injuries. Moreover, this type of evacuation had never been carried out before on the face of this earth, and it is an evacuation that was quite different in kind and quality than one undertaken in time of flood or hurricane or tornado. . . . When you talk about evacuating people within a 5-mile radius of the site of a nuclear reactor, you must recognize that that will have 10-mile consequences, 20-mile consequences, 100-mile consequences, as we heard during the course of this event. This is to say, it is an event that people are not able to see, to hear, to taste, to smell. . . .90/

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Relations between reporters and Met Ed officials had deteriorated over several days. Many reporters suspected the company of providing them with erroneous information at best, or of outright lying. When John Herbein arrived at 11:00 a.m. Friday to brief reporters gathered at the American Legion Hall in Middletown, the situation worsened. The press corps knew that the radioactivity released earlier had been reported at 1,200 millirems per hour; Herbein did not. He opened his remarks by stating that the release had been measured at around 300 to 350 millirems per hour by an aircraft flying over the Island. The question-and-answer period that followed focused on the radiation reading -- "I hadn't heard the number 1,200," Herbein protested during the news conference -- whether the release was controlled or uncontrolled, and the previous dumping of radioactive wastewater. At one point Herbein said, "I don't know why we need to tell you each and every thing that we do specifically. . . ."91/ It was that remark that essentially eliminated any credibility Herbein and Met Ed had left with the press.92/

The next day, Jack Watson, a senior White House aide, would telephone Herman Dieckamp, president of Met Ed's parent company, to express his concern that the many conflicting statements about TMI-2 reported by the news media were increasing public anxiety. Watson would suggest that Denton alone brief reporters on the technical aspects of the accident and Dieckamp would agree.93/

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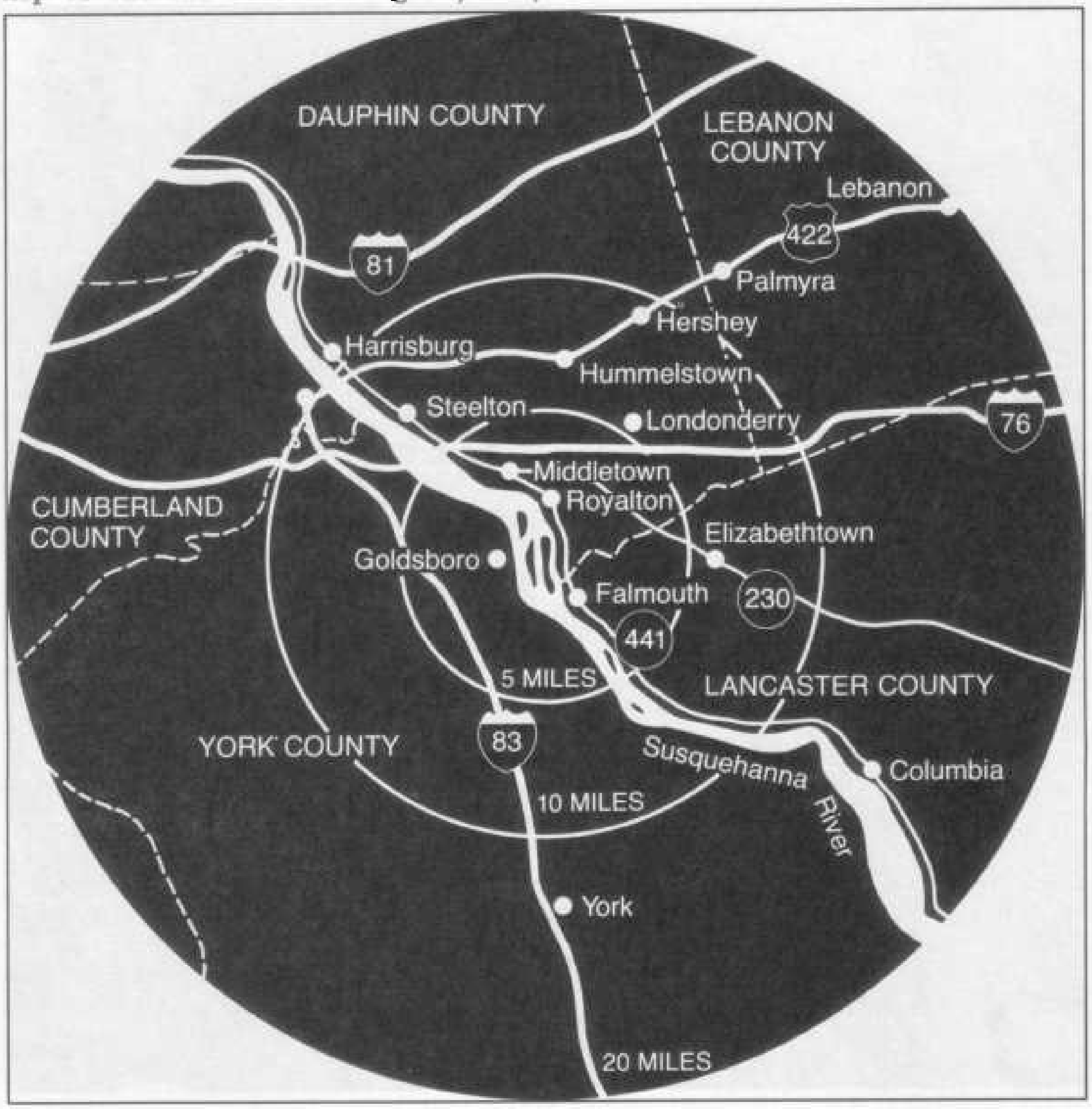
The radiation release, Molloy's announcement of a probable evacuation, and finally the Governor's advisory brought concern and even fear to many residents. Some people had already left, quietly evacuating on their own; others now departed. "On March 29 of this year, my wife and I joyously brought home our second daughter from the hospital; she was just 6 days old," V.T. Smith told the Commission.

Governor Richard Thornburgh testifying before the Commission.

Man of the TMI area showing 5-. 10-, and 20-mile evacuation zones.



"On the morning of the 30th, all hell broke loose and we left for Delaware to stay with relatives." 94/ By Saturday evening, a Goldsboro councilman estimated 90 percent of his community's residents had left.95/

Schools closed after the Governor's advisory. Pennsylvania State University called off classes for a week at its Middletown campus. Friday afternoon, " . . . still having heard nothing from Three Mile Island," Harrisburg Mayor Paul Doutrich drove with his deputy public works director to the TMI Observation Center overlooking the nuclear facility. There they talked for an hour with Met Ed President Creitz and Vice President Herbein. "Oddly enough, one of the things that impressed me the most and gave me the most feeling of confidence that things were all right was that everybody in that area, all the employees, the president and so forth, were walking around in their shirt sleeves, bare-headed," Doutrich told the Commission. "I saw not one indication of nuclear protection."96/

Friday, Saturday, and Sunday were hectic days in the emergency preparedness offices of the counties close to Three Mile Island. Officials labored first to prepare 10-mile evacuation plans and then ones covering areas out to 20 miles from the plant. The Pennsylvania Emergency Management Agency recommended Friday morning that 10-mile plans be readied. The three counties closest to the nuclear plant already had plans to evacuate their residents -- a total of about 25,000 living within 5 miles of the Island. A 10-mile evacuation had never been contemplated. For Kevin Molloy in Dauphin County, extending the evacuation zone meant the involvement of several hospitals -- something he had not confronted earlier. There were no hospitals within 5 miles. Late Friday night, PEMA told county officials to develop 20-mile plans. Suddenly, six counties were involved in planning for the evacuation of 650,000 people, 13 hospitals, and a prison.97/

Friday was also the day the nuclear industry became deeply involved in the accident. After the radiation release that morning, GPU President Dieckamp set about assembling an industry team to advise him in managing the emergency. Dieckamp and an aide talked with industry leaders around the country, outlining the skills and knowledge needed at TMI-2. By late Saturday afternoon, the first members of the Industry Advisory Group had arrived. They met with Dieckamp, identified the tasks that needed immediate attention, and decided who would work on each.98/

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Harold Denton arrived on site about 2:00 p.m. Friday, bringing with him a cadre of a dozen or so experts from NRC headquarters. Earlier in the day, NRC had learned of the hydrogen burn or explosion that flashed through the containment building Wednesday afternoon. The NRC staff already knew that some form of gas bubble existed within the reactor system. Now it became obvious that the bubble, an estimated 1,000 cubic feet of gases, contained hydrogen. And as Denton would later recall in his deposition, the question arose whether there was a potential for a hydrogen explosion. Throughout

Friday, Denton operated on estimates provided him before he left Bethesda, which indicated that the bubble could not self-ignite for 5 to 8 days. Denton focused his immediate attention on finding ways to eliminate the bubble.99/

At about 8:30 p.m. Friday, Denton briefed Governor Thornburgh in person for the first time. Fuel damage was extensive; the bubble posed a problem in cooling the core; no immediate evacuation was necessary, Denton said. Then the two men held their first joint press conference. The Governor reiterated that no evacuation was needed, lifted his advisory that people living within 10 miles of Three Mile Island stay indoors, but continued his recommendation that pregnant women and preschool children remain more than 5 miles from the plant.100/

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Shortly after 4:00 p.m., Jack Watson, President Carter's assistant for intergovernmental affairs, called Jay Waldman, Governor Thornburgh's executive assistant. The two disagree about the substance of that call. In an interview with the Commission staff, Waldman said Watson asked that the Governor not request President Carter to declare a state of emergency or disaster:

> He said that it was their belief that that would generate unnecessary panic, that the mere statement that the President has declared this area an emergency and disaster area would trigger a substantial panic; and he assured me that we were getting every type and level of federal assistance that we would get if there had been a declaration. I told him that I would have to have his word on that, an absolute assurance, and that if that were true, I would go to the Governor with his request that we not formally ask for a declaration.101/

Watson and his assistant, Eugene Eidenberg, both said in their Commission depositions that the White House never asked Governor Thornburgh not to request such a declaration. 102/ Whatever was said in that Friday conversation, the Governor made no request to the President for an emergency declaration. State officials later expressed satisfaction with the assistance provided by the federal government during the accident and immediately after. They were less satisfied, however, in August with the degree of assistance and cooperation they were receiving from federal agencies.103/

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Officials of the U.S. Department of Health, Education, and Welfare (HEW) had become concerned about the possible release of radioactive iodine at Three Mile Island and began Friday to search for potassium iodide -- a drug capable of preventing radioactive iodine from lodging in the thyroid. The thyroid absorbs potassium iodide to a level where the gland can hold no more. Thus, if a person is exposed to radioactive iodine after receiving a sufficient quantity of potassium iodide, the thyroid is saturated and cannot absorb the additional iodine with its potentially damaging radiation. At the time of the TMI-2 accident, however, no pharmaceutical or chemical company was marketing medical-grade potassium iodide in the quantities needed.104/

Saturday morning, shortly after 3:00 a.m., the Mallinckrodt Chemical Company agreed to provide HEW with approximately a quarter million one-ounce bottles of the drug. Mallinckrodt in St. Louis, working with Parke-Davis in Detroit and a bottle-dropper manufacturer in New Jersey, began an around-the-clock effort. The first shipment of potassium iodide reached Harrisburg about 1:30 a.m. Sunday. By the time the last shipment arrived on Wednesday, April 4, the supply totalled 237,013 bottles.105/

SATURDAY, MARCH 31

The great concern about a potential hydrogen explosion inside the TMI-2 reactor came with the weekend. That it was a groundless fear, an unfortunate error, never penetrated the public consciousness afterward, partly because the NRC made no effort to inform the public it had erred.106/

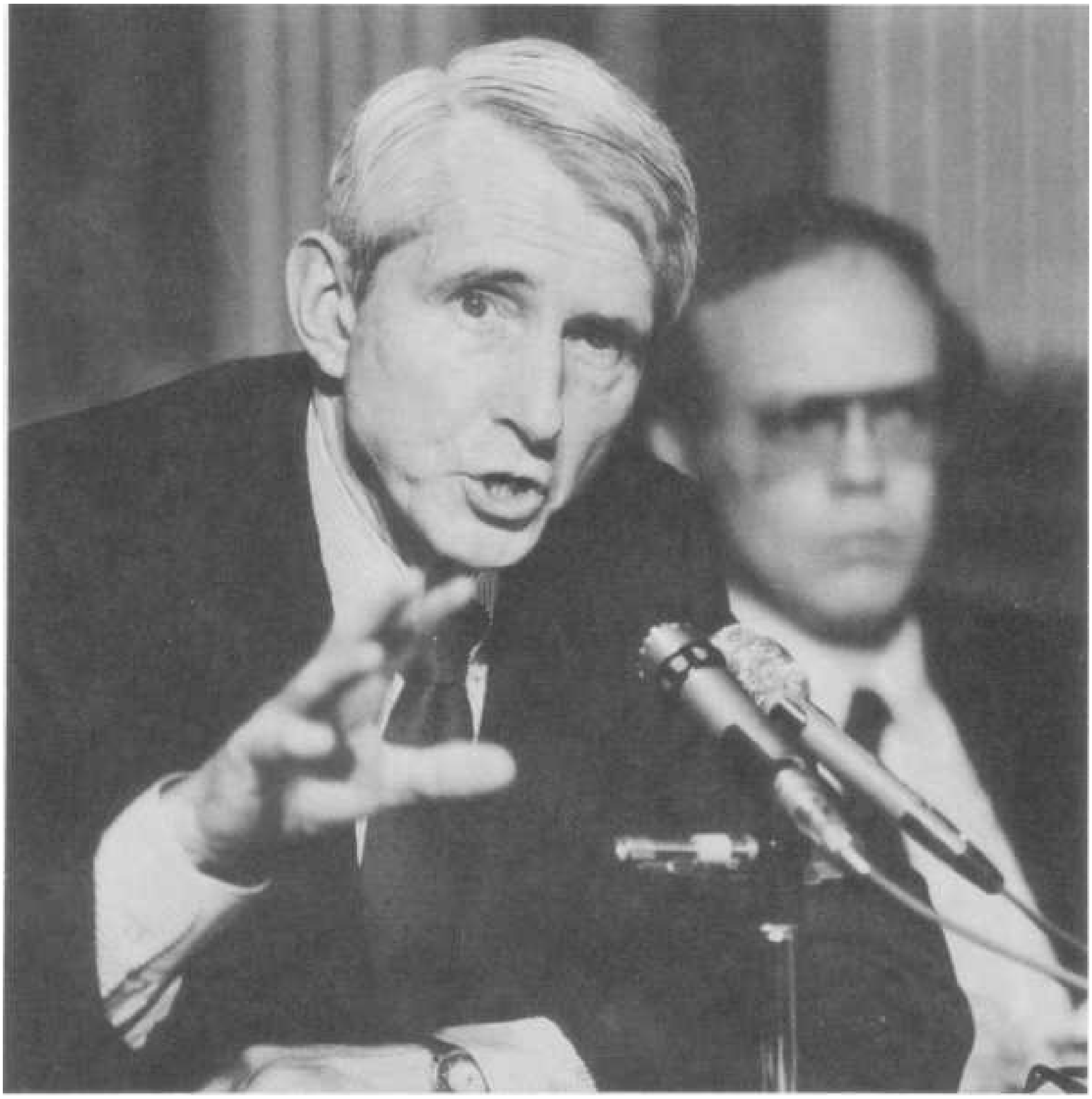
Around 9:30 p.m. Friday night, the NRC chairman asked Roger Mattson to explore the rate at which oxygen was being generated inside the TMI-2 reactor system and the risk of a hydrogen explosion. "He said he had done calculations," Mattson said in his deposition. "He was concerned with the answers."107/ Mattson is director of the Division of Systems Safety within the Office of Nuclear Reactor Regulation (NRR), which is headed by Denton, and had spent part of Thursday and Friday working on how to remove a gas bubble from the reactor. Following Denton's departure for TMI, Mattson served variously as NRR's representative or deputy representative at the Incident Response Center.

Hydrogen had been produced in the reactor as a result of a high-temperature reaction that occurred between hot steam and the zirconium cladding of the fuel rods. For this hydrogen to explode or burn -- a less dangerous possibility -- enough oxygen would have to enter the system to form an explosive mixture. There were fears this would happen as the result of radiolysis. In this process, radiation breaks apart water molecules, which contain hydrogen and oxygen.

Two NRC teams worked throughout the weekend on the problem, and both sought help from laboratories and scientists outside the NRC. One group addressed the rate at which radiolysis would generate oxygen at TMI-2. The second analyzed the potential for hydrogen combustion. Robert Budnitz of the NRC also asked experts about possible chemicals that might remove the hydrogen.

At noon, Hendrie talked by telephone with Denton and expressed his concern that oxygen freed by radiolysis was building up in the reactor. Earlier, Hendrie had told Victor Stello, Jr., Denton's second-in-command at TMI, the same thing. The NRC chairman told

NRC Chairman Joseph Hendrie testifying at a Commission hearing.



Harold Denton, director of NRC's Office of Nuclear Reactor Regulation, and Governor Thornburgh at a March 31 news conference in Harrisburg.

Denton that Governor Thornburgh should be made aware of the potential danger. Denton promised to speak with Thornburgh.

Shortly after 1:00 p.m., Mattson got some preliminary answers regarding the potential for a hydrogen explosion. An hour later, Mattson got more replies. "I had an estimate there was oxygen being generated, from four independent sources, all with known credentials in this field," he said in his deposition. "The estimate of how much oxygen varied, but all estimates said there was considerable time, a matter of several days, before there was a potential combustible mixture in the reactor coolant system."108/

At a Commission hearing, Mattson later admitted in response to questions from Commissioner Pigford that the NRC could have determined from the information available at that time that no excess oxygen was being generated and there was no real danger of explosion.109/ But when Mattson met with the NRC commissioners at 3:27 p.m. on Saturday, "the bottom line of that conversation . . . was there were several days required to reach the flammability limit, although there was oxygen being generated," Mattson recalled in his deposition. "And I expressed confidence that we were not underestimating the reactor coolant system explosion potential; that is, the estimate of 2 to 3 days before reaching the flammability limit was a conservative estimate." By Saturday night, however, Mattson would be told by his consultants that their calculations indicated that the oxygen percentage of the bubble was on the threshold of the flammability limit.110/

Around 6:45 p.m., Mattson talked with Vincent Noonan, the man within NRC most knowledgeable about what might result from an explosion inside a reactor. One NRC consultant had predicted that a hydrogen blast would produce pressures of 20,000 pounds per square inch within the TMI-2 reactor. B&W, designer of the reactor, however, had considered the dampening effects of water vapor on an explosion and those of an enriched hydrogen environment and calculated a total pressure of 3,000 to 4,000 psi. That was encouraging. Previous analyses indicated the reactor coolant system of a TMI-2 reactor could withstand blast pressures of that magnitude.

Late Saturday evening, James Taylor of B&W reiterated another B&W engineer's conclusion first relayed to the NRC Thursday night -- that no excess oxygen was being generated. That information, Mattson stated in his deposition, never reached him.111/

Saturday at 2:45 p.m., Hendrie met with reporters in Bethesda. He said then that a precautionary evacuation out to 10 or 20 miles from the Island might be necessary if engineers attempted to force the bubble out of the reactor. NRC had concluded such an attempt might cause further damage to the core, Hendrie said, and it might touch off an explosion of the bubble.

Stan Benjamin, a reporter with the Washington bureau of the Associated Press, followed up Hendrie's press conference by interviewing two NRC officials: Edson Case, Denton's deputy in the Office of Nuclear Reactor Regulation, and Frank Ingram, a public information spokesman. From them, and an NRC source he refused to name, Benjamin learned of the concern within the Incident Response

Center that the bubble could become a potentially explosive mixture within a matter of days, perhaps as few as two. Benjamin checked his story with Case and Ingram, reading much of it to them word by word, before releasing the article. Case and Ingram agreed it was accurate. The report -- first transmitted as an editor's note at 8:23 p.m. -- was the first notice to the public that some NRC officials feared the bubble might possibly explode spontaneously.112/

Denton had been briefed throughout Saturday afternoon and evening by Hendrie and NRC officials in Bethesda on the oxygen estimates and the potential for a burn or explosion. But he learned of the AP story only a short time before he joined Governor Thornburgh and Lieutenant Governor Scranton for a late evening press conference in Harrisburg. The Governor assured reporters that "there is no imminent catastrophic event foreseeable at the Three Mile Island facility." Denton, too, said: "There is not a combustible mixture in the containment or in the reactor vessel. And there is no near-term danger at all." Denton also tried to deflate the impression, voiced by several reporters, that contradictions existed between himself and his colleagues at NRC headquarters. "No, there is no disagreement. I guess it is the way things get presented," he said.113/

But there was disagreement, and Denton wanted it resolved. President Carter had announced earlier in the evening he would visit TMI the following day. Denton told Stello to explore the oxygen-hydrogen issue further with outside experts. Stello realized the concern in Washington. He had received a telephone call shortly after 9:00 p.m. from Eugene Eidenberg, a Presidential aide, inquiring about the AP story. Stello told the White House that he did not share the concern felt at NRC headquarters.

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Saturday, as the NRC wrestled with managing the accident and the envisioned danger of the hydrogen bubble, officials of the Department of Health, Education, and Welfare struggled with their own concerns. That morning, senior HEW health officials gathered and continued the previous day's discussion of the possibility of an evacuation; for the first time, they debated how large an area should be evacuated. But the discussions led ultimately to a recommendation to consider immediate evacuation if the NRC could not provide assurances that the reactor was cooling safely. Joseph Califano, HEW Secretary, summarized the group's views in a memorandum to Jack Watson of the President's staff.

Later in the day, HEW health officials attended an interagency meeting at the White House, convened by Watson, and repeated the HEW recommendation to consider evacuation. Richard Cotton, a key Califano aide, raised another Califano recommendation that NRC officials consult with HEW and Environmental Protection Agency experts regarding the potential health effects of the efforts to control TMI-2's reactor. Cotton persisted after the meeting, and on Sunday and Tuesday HEW officials were briefed by the NRC. These briefings, however, were always informational; there was no NRC effort to seek HEW's advice.114/

SUNDAY, APRIL 1

Throughout Saturday night and the early hours of Sunday, county emergency preparedness offices were deluged with telephone calls from citizens concerned by the conflicting reports about the hydrogen bubble. But the flow of useful information from the state to the local level had essentially ceased after Denton's arrival. The Governor's office focused attention on the federal effort -- Denton and officials from several U.S. emergency agencies. Oran Henderson, director of the Pennsylvania Emergency Management Agency, was no longer invited to the Governor's briefings and press conferences, and he did not attend after Friday night. Thus PEMA -- although it continued to receive status reports from the Bureau of Radiation Protection -- was isolated from information wanted at the local level.

In Dauphin County, frustration ran high. Shortly before midnight on Saturday, State Sen. George Gekas called the Governor in an attempt to obtain accurate information. Gekas was told the Governor was too busy to talk. Then Gekas called Scranton, and got the same response. At that point, Gekas told a Scranton aide that unless more cooperation and information were forthcoming, Dauphin County would order an evacuation at 9:00 a.m. Sunday. Scranton called the county's emergency center at 2:00 a.m. and agreed to meet officials there later in the morning. The Lieutenant Governor arrived at 10:00 a.m., preceded by Henderson, who complained of his own inability to obtain information. Scranton listened to Molloy and his colleagues. "I think he was just totally shocked by what was transpiring at our level; how busy we were; how much work we were doing; how complicated it was," Molloy said in his deposition.115/

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Sunday, Mattson and several other NRC staffers met with NRC Commissioners Hendrie, Victor Gilinsky, and Richard Kennedy. Their purpose was to reach a judgment, based on the estimates and information available, about the true potential for a hydrogen explosion inside the reactor. According to Mattson's deposition, the group agreed:

President Jimmy Carter touring the TMI-2 control room with (1 to r) Harold Denton, Governor Thornburgh, and James Floyd, supervisor of TMI-2 operations, on April 1.

> 5 percent oxygen was a realistic flammability limit, 11 percent oxygen was a realistic detonation limit, that there could be no spontaneous combustion below 900°F, that the oxygen production rate was approximately one percent per day, and that the present oxygen concentration in the bubble was 5 percent.116/

After the meeting, Hendrie and Mattson drove to TMI to meet with Denton.

Stello talked with Denton Sunday morning and outlined his arguments against any danger of a hydrogen explosion inside the reactor. Pressurized water reactors, the type used at TMI-2, normally operate with some free hydrogen in the reactor coolant. This hydrogen joins with the oxygen freed by radiolysis to form another water molecule, which prevents the build-up of oxygen to a quantity that would allow an explosion to take place. Stello told Denton that the process was the same now, and there was no danger of explosion.

Hendrie and Mattson met with Denton and Stello in a hangar at Harrisburg International Airport minutes before President Carter's 1:00 p.m. arrival. Mattson and Stello had not talked to each other since Friday morning. Mattson outlined the conclusions reached at NRC headquarters about the bubble and the reasoning behind them. In an interview with the Commission staff, Mattson described what happened next:

> And Stello tells me I am crazy, that he doesn't believe it, that he thinks we've made an error in the rate of calculation . . . . Stello says we're nuts and poor Harold is there, he's got to meet with the President in 5 minutes and tell it like it is. And here he is. His two experts are not together. One comes armed to the teeth with all these national laboratories and Navy reactor people and high faluting PhDs around the country, saying this is what it is and this is his best summary. And his other [the operating reactors division] director, saying, "I don't believe it. I can't prove it yet, but I don't believe it. I think it's wrong."117/

Upon the President's arrival, Denton briefed the Chief Executive on the status of the plant and the uncertainty regarding its infamous bubble.

The President was driven to TMI, put on protective yellow plastic shoecovers, and toured the facility with Mrs. Carter, Governor Thornburgh, and Denton. Stello, Hendrie, and Mattson went to the temporary NRC offices. During the afternoon, experts -- including those at Westinghouse and General Electric -- were canvassed by phone. "By three o'clock, we're convinced we've got it," Mattson said in his interview. "It's not going to go boom."118/

NRC scientists in Bethesda eventually reached the same conclusion, but later in the day. Shortly before 4:00 p.m., NRC Commissioners Richard Kennedy, Peter Bradford, and John Ahearne met. They expressed concern over the differing estimates presented by the NRC staff and decided there might be a need to consider evacuation.

Kennedy telephoned Hendrie at TMI and told him the three NRC Commissioners thought Governor Thornburgh should advise a precautionary evacuation within 2 miles of the plant, unless experts on-site had better technical information than that available in Bethesda.119/ Hendrie assured Kennedy that the free hydrogen inside the reactor would capture any oxygen generated and that no problem existed.

In midafternoon, new measurements showed the large bubble in the reactor was diminishing. The gases still existed, but they were distributed throughout the system in smaller bubbles that made eliminating the predominantly hydrogen mixture easier. Why this occurred, no one knows. But it was not because of any intentional manipulation by Met Ed or NRC engineers.

By late Sunday afternoon, NRC -- which was responsible for the concern that the bubble might explode -- knew there was no danger of a blast and that the bubble appeared to be diminishing. It was good news, but good news unshared with the public. Throughout Sunday, the NRC made no announcement that it had erred in its calculations or that no threat of an explosion existed. Governor Thornburgh was not told of the NRC miscalculation either. Nor did the NRC reveal the bubble was disappearing that day, partly because the NRC experts themselves were not absolutely certain.

MONDAY, APRIL 2

Monday morning Denton and Mattson met the press. George Troffer, a Met Ed official, had already told a reporter the bubble was essentially gone. Denton acknowledged a "dramatic decrease in bubble size," but cautioned that more sophisticated analyses were needed "to be sure that the equations that are used to calculate bubble size properly include all effects." As to the bubble's potential for explosion, Denton told reporters "the oxygen generation rate that I was assuming yesterday when I was reporting on the potential detonation inside the vessel is, it now appears, to have been too conservative." Throughout the press conference, Denton continued to refer to NBC's estimates as too conservative; he never stated outright that NRC had erred in its conclusion that the bubble was near the dangerous point.120/

According to Mattson, the tone of the press conference -- its vagueness and imprecision -- was decided upon at a meeting of NRC officials Monday morning.

> We wanted to go slow on saying it was good news. We wanted to say it is good news, do not panic, we think we have got it under control, things look better, but we did not want to firmly and finally conclude that there was no problem. We had to save some wiggle room in order to preserve credibility. That was our judgement."121/

Harold Denton at an April 2 press conference. The bearded man behind Denton is Roger Mattson, director of NRC's Division of Systems Safety. Beside Denton is Joseph Fouchard, NRC's public affairs director.

EPILOGUE

The accident at Three Mile Island did not end with the breaking up of the bubble, nor did the threat to the health and safety of the workers and the community suddenly disappear. A small bubble remained, gases still existed within TMI-2's cooling water, and the reactor itself was badly damaged. Periodic releases of low-level radiation continued, and some feared a major release of radioactive iodine-131 might yet occur. Schools remained closed. The Governor's recommendation that pregnant women and preschool children stay more than 5 miles from the plant continued.

Saturday, March 31, the Department of Health, Education, and Welfare had arranged for the rapid manufacture of nearly a quarter million bottles of potassium iodide. 122/ That same day, the Pennsylvania Bureau of Radiation Protection -- which had originally accepted HEW's offer to obtain the drug -- transferred responsibility for handling the radioactive iodine blocker to the state's Department of Health. Gordon MacLeod, who headed the health department, put the drug shipments in a warehouse as they began arriving Sunday. During the weekend, Thomas Gerusky, director of the Bureau of Radiation Protection, requested that his people at TMI be issued potassium iodide; Gerusky wanted BRP personnel to have the thyroid-blocking agent available should a release of radioactive iodine occur. MacLeod refused. He argued that if the public learned that any of the drug had been issued, a demand for its public distribution would result.

MacLeod had the backing of the Governor's office and Harold Denton in his decision not to issue the potassium iodide. The decision did not find agreement in Washington, however. On Monday, Jack Watson asked HEW to prepare recommendations for the drug's distribution and use. These were developed by a group headed by Donald Frederickson, director of the National Institutes of Health. The recommendation included: administering potassium iodide immediately to all workers on the Island; providing the drug to all people who would have less than 30 minutes' warning of a radioactive iodine release (roughly those within 10 miles of the plant); and that local authorities assess these recommendations in light of their first-hand knowledge of the situation.

Governor Thornburgh received the recommendations in a White House letter on Tuesday, although some Pennsylvania officials had learned of them Monday. MacLeod strongly opposed distributing the drug to the public. Among his reasons: radioiodine levels were far below what was indicated for protective action, and the likelihood of a high-level release from TMI-2 was diminishing; distributing the drug would increase public anxiety and people might take it without being told to do so; and the possibility of adverse side-effects presented a potential public health problem in itself. MacLeod chose not to accept the federal recommendations. The potassium iodide remained in a warehouse under armed guard throughout the emergency. In midsummer, the FDA moved the drug to Little Rock, Arkansas, for storage.

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Tuesday, April 3, General Public Utilities, Met Ed's parent company, established its TMI-2 recovery organization to oversee and direct the long process of cleaning up TMI-2. Robert Arnold, a vice president of another subsidiary, the GPU Service Corporation, was named to head the recovery operation.123/

Wednesday, April 4, schools outside the 5-mile area surrounding TMI reopened. All curfews were lifted. But schools within 5 miles of the Island remained closed and the Governor's advisory remained in effect for pregnant women and preschool children.

Some sense of normalcy was gradually returning to the TMI area. Governor Thornburgh asked Denton repeatedly if the advisory could be lifted, allowing pregnant women and preschool children to return home. But the NRC wanted some specific event as a symbol to announce the crisis had ended. At first, the NRC looked to reaching "cold shutdown" -- the point at which the temperature of TMI-2's reactor coolant fell below the boiling point of water. When it became obvious that cold shutdown was days away, agreement was reached between Pennsylvania's Bureau of Radiation Protection and the NRC on ending the advisory. On Saturday, April 7, Kevin Molloy, at the request of the Governor's office, read a press release announcing the closing of the evacuation shelter at the Hershey Park Arena. Not until 2 days later, however, did Governor Thornburgh officially withdraw the advisory.124/

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The accident at TMI did not end with cold shutdown, nor will it end for some time. More than a million gallons of radioactive water remain inside the containment building or stored in auxiliary building tanks. The containment building also holds radioactive gases and the badly damaged and highly radioactive reactor core. Radioactive elements contaminate the walls, floors, and equipment of several buildings. Ahead lies a decontamination effort unprecedented in the history of the nation's nuclear power industry -- a cleanup whose total cost is estimated at $80 to $200 million and which will take several years to complete.125/

The potassium iodide supplies in a Harrisburg warehouse.

TMI personnel cleaning up the contaminated auxiliary building.

The initial cleanup began in April. Using a system called EPICOR-I, Met Ed began decontaminating pre-accident water stored in the TMI-1 auxiliary building, which contains low levels of radioactivity (less than one microcurie per milliliter). Efforts to decontaminate the TMI-2 diesel generation building began in April and work on the auxiliary and fuel handling buildings got under way in May. This involves mostly dry and wet vacuuming, mopping, and wiping of radioactive areas to remove the contamination -- a task that requires special clothing and respirators to protect workers.

The accident and its subsequent cleanup already have produced a variety of solid, slightly radioactive wastes, such as clothing, rags, ion-exchange resins, swipes, and contaminated air filters. To date, 12 truckloads of these wastes have been hauled to Richland, Washington, and buried at a commercial disposal site.

But the more difficult aspects of decontamination -- both technically and politically -- lie ahead. Met Ed has asked the NRC for permission to release the krypton-85 in the air of the containment building into the atmosphere in controlled bursts. The releases would come over a 2-month period to ensure that off-site radiation does not exceed the NRC's limits for routine operation of a nuclear power plant.

Much of the contaminated water left from the accident -- some 600,000 gallons pooled in the containment building and about 90,000 gallons in the reactor coolant system -- contains high levels of radioactivity (in excess of 100 microcuries per milliliter). Met Ed had stored 380,000 gallons of water containing intermediate levels of radioactivity (1 to 100 microcuries per milliliter) in several TMI-2 auxiliary building tanks. Over the summer, the utility installed a system called EPICOR-II to treat this water. NRC approved its use, provided that the resins used to remove radioactive materials from the water were solidified before shipment from the Island to a disposal site. Met Ed began decontaminating the intermediate water in mid-October.

Until radioactive gases are removed from the containment building, no human entry into the sealed structure can be made. Meanwhile, detailed plans for entry and assessing conditions inside the building are being developed. Because no one knows the exact condition of the reactor vessel or its core, no detailed plans have been made for handling and removing its damaged core.

Thus, the accident at Three Mile Island, in a very real sense, continues and will continue until the years-long cleanup of TMI-2 is completed. Workers will receive additional radiation doses until the decontamination process is completed; five workers in late August, for example, received doses in excess of the NRC's quarterly limits for exposure to the skin or the extremities. And there still remains some risk to the general public that released radiation could escape from the Island.

FOOTNOTES

1. For times cited in narrative, please refer to the "Catalog of Events" compiled by the Commission's Technical Assessment Task Force. This unpublished document is available with the Commission's official records in the National Archives.

2. Commission Hearing, May 19, 1979, pp. 24, 27-28. For a discussion of the mental health effects of the TMI accident, see "Report of the Behavioral Effects Task Group."

3. General Public Utilities Corporation, 1978 Annual Report. For a full discussion of the Commission's investigation of GPU and its subsidiary, Metropolitan Edison, see "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

4. **See** history section of "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission."

5. See "How a Nuclear Reactor Works," a lecture presented by Commissioner Theodore B. Taylor to members of the Commission, April 26, 1979.

6. Final Safety Analysis Report, TMI-2, Vol. 4, pp. 4.2-37, 4.3-20. See also Taylor, supra.

7. Final Safety Analysis Report, TMI-2, Vol. 4, pp. 4.2-4, 4.2-5, 4.3-19; figures 4.2-4, 4.3-25, 4.2-26; and Vol. 7, p. 7.8-3; figure 7.8-4.

8. See Taylor, supra. See also technical staff analysis report on "Alternative Event Sequences."

9. Final Safety Analysis Report, TMI-2, Vol. 3, p. 3.8-38.

10. See technical staff analysis reports on "Core Damage," "Chemistry," "Thermal Hydraulics," and "Alternative Event Sequences."

11. For a complete discussion of the pilot-operated relief valve, see technical staff analysis report on "Pilot-Operated Relief Valve

Design and Performance," and section on PORV failure history in "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers." See also discussion of "safety-related" items in "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission."

12. Commission Hearing, May 30, 1979, pp. 10, 115, 152-153.

13. For a full discussion of Metropolitan Edison's and Babcock & Wilcox's treatment of problems associated with pilot-operated relief valves, see "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

14. For a discussion on operator training, see technical staff analysis report on "Selection, Training, Qualification, and Licensing of Three Mile Island Reactor Operating Personnel." See also technical staff analysis report on "Technical Assessment of Operating, Abnormal, and Emergency Procedures;" and sections on attention to experience, TMI-2 site management, and procedures in "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers;" and section on operator training and licensing in "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission."

15. Id.

16. For a full discussion of the control room, see technical staff analysis report on "Control Room Design and Performance." See also "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers" for a discussion of the TMI-2 control room design history and design performance during the accident; and "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission" on the NRC's consideration of human factors in design review during plant licensing.

17. Commission Hearing, May 30, 1979, p. 168.

18. See technical staff analysis report on "Condensate Polishing System." See also section on attention to experience in "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

19. For a discussion on operator training, see technical staff analysis report on "Selection, Training, Qualification, and Licensing of Three Mile Island Reactor Operating Personnel." See also technical staff analysis report on "Technical Assessment of Operating, Abnormal, and Emergency Procedures;" and sections on attention to experience, TMI-2 site management, and procedures of "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers;" and section on operator training and licensing in "Report of the Office of Chief Counsel on the Nuclear Regultory Commission."

20. Commission Hearing, May 30, 1979, p. 168.

21. See technical staff analysis report on "Technical Assessment of Operating, Abnormal, and Emergency Procedures." See also discussion of pressurizer level and "going solid" in procedures section of "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

22. Commission Hearing, May 30, 1979, p. 194.

23. Commission Hearing, May 30, 1979, pp. 114-115; Commission Hearing, May 31, 1979, p. 40.

24. See technical staff analysis report on "Closed Emergency Feedwater Valves."

25. See technical staff analysis report on "Technical Assessment of Operating, Abnormal, and Emergency Procedures." See also discussion of emergency procedures for loss of reactor coolant and for identifying the open pilot-operated relief valve in procedures section of "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

26. Commission Hearing, May 30, 1979, p. 128.

27. Commission Hearing, May 30, 1979, p. 129.

28. See technical staff analysis report on "Technical Assessment of Operating, Abnormal, and Emergency Procedures." See also discussion of emergency procedures for loss of reactor coolant and for identifying the open pilot-operated relief valve in procedures section of "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

29. Commission Hearing, May 30, 1979, p. 146.

30. See unpublished "Catalog of Events."

31. Commission Hearing, May 31, 1979, p. 38.

32. Commission Hearing, May 30, 1979, p. 187.

33. Commission Hearing, May 30, 1979, p. 161.

34. See technical staff analysis reports on "Core Damage," "Thermal Hydraulics," and "Chemistry." See also section on Met Ed's understanding of core condition on March 28 in "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

35. Rogers deposition, pp. 84-85.

36. Commission Hearing, May 30, 1979, pp. 119-120.

37. See technical staff analysis reports on "Core Damage" and "Chemistry."

38. Final Safety Analysis Report, TMI-2, Vol. 13, p. 13A-3..

39. Commission Hearing, May 31, 1979, pp. 6-7.

40. Prepared testimony of Gary Miller, Commission Hearing, May 31, 1979: "TMI Station March 28, 1979, Incident Statement by G. P. Miller, Station Manager," pp. 3-4.

41. NRC Region I answering service log. For a complete discussion of the emergency response during the TMI accident, see "Report of the Office of Chief Counsel on Emergency Response," which is in the form of a chronology. See also "Technical Report on Emergency Preparedness and Response." For a discussion of Met Ed's management of the accident, see section on management approach to the emergency of "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

42. Dornsife deposition, p. 20.

43. Final Safety Analysis Report, TMI-2, Vol. 13, p. 13A-4.

44. For a discussion of containment and isolation, see technical staff analysis report on "Containment."

45. Mattson deposition, pp. 12-14. For a complete discussion of "grandfathering" and other matters related to plant licensing, see section on plant licensing in "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission."

46. For a complete discussion on selection of containment isolation criteria for TMI-2, see section on containment isolation criteria in "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

47. See technical staff analysis report on "Containment."

48. Commission Hearing, May 31, 1979, p. 51.

49. Commission staff notes of Pintek interview, pp. 1-2.

50. For a discussion of news media coverage of the TMI accident, see "Report of the Public's Right to Information Task Force."

51. Commission Hearing, May 19, 1979, p. 125.

52. Commission Hearing, May 31, 1979, pp. 236-237.

53. In addition to unpublished "Catalog of Events," please refer to "Report of the Office of Chief Counsel on Emergency Response" for times and dates cited.

54. Commission Hearing, May 19, 1979, p. 15.

55. Commission Hearing, August 2, 1979, pp. 180-183.

56. Transcript of Scranton news conference, March 28, 1979, 10:55 a.m.

57. Id. For a discussion on radiation exposure to the public during the accident and its potential health effects, see "Report of the Health Physics and Dosimetry Task Group" and "Report of the Radiation Health Effects Task Group."

58. Commission Hearing, August 2, 1979, p. 184. See also discussion of information sources in "Report of the Public's Right to Information Task Force."

59. See technical staff analysis reports on "Thermal Hydraulics," "Chemistry," and "Technical Assessment of Operating, Abnormal, and Emergency Procedures." See also discussion of rapid depressurization in emergency response section of "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission."

60. For a discussion of the radiation exposure to workers during the accident, see "Report of the Health Physics and Dosimetry Task Group." For a discussion on NRC requirements for Met Ed's provisions for worker protection, see "Report of the Public Health and Epidemiology Task Group."

61. Commission Hearing, May 31, 1979, p. 57.

62. Commission Hearing, May 31, 1979, p. 58.

63. Rogers deposition, p. 114.

64. Commission Hearing, May 31, 1979, p. 59.

65. For a discussion on radiation exposure to the public during the accident and its potential health effects, see "Report of the Health Physics and Dosimetry Task Group" and "Report of the Radiation Health Effects Task Group."

66. Governor's log, March 28, 1979, p. 3.

67. Transcript of Scranton news conference, March 28, 1979, 4:30 p.m.

68. Id.

69. Commission Hearing, May 19, 1979, pp. 37, 41.

70. Dauphin County Office of Emergency Preparedness log, March 29, 1979.

71. For a discussion of radiation monitoring during the accident, see "Report of the Health Physics and Dosimetry Task Group."

72. MacLeod deposition, pp. 21-26.

73. Robbins deposition, pp. 36-37.

74. MacLeod deposition, pp. 29-36.

75. Reilly interview, pp. 92-94; Gallina deposition, pp. 56-57; Smith deposition, p. 36; and Gerusky interview, pp. 24-25. See also "Report of the Public's Right to Information Task Force."

76. NRC telephone transcript, March 29, 1979, 02-228-CH6/KD-2-6.

77. Pennsylvania DER news release, March 29, 1979. See also "Report of the Public's Right to Information Task Force" and "Report of the Office of Chief Counsel on Emergency Response."

78. Higgins deposition, pp. 42, 45-46; Gallina deposition, p. 60; Critchlow interview, first and second tape, pp. 15-18.

79. Barrett deposition, pp. 39-50.

80. Commission Hearing, August 2, 1979, pp. 316.

81. Commission Hearing, May 31, 1979, pp. 172-181.

82. Commission Hearing, August 2, 1979, pp. 298-299.

83. Id., pp. 303-316.

84. Collins deposition, pp. 70-72; Scranton interview, p. 54; Gerusky deposition, pp. 53-54; Dornsife deposition, p. 76; NRC telephone transcript, March 30, 1979, 03-019-CH2.20 SW-10.

85. Molloy deposition, pp. 48-49; Commission Hearing, August 2, 1979, pp. 10-11.

86. Commission Hearing, May 31, 1979, pp. 257-258.

87. Thornburgh deposition, p. 77.

88. Commission Hearing, August 21, 1979, p. 10.

89. Gerusky deposition, pp. 64-65, 67.

90. Commission Hearing, August 21, 1979, p. 25.

91. Transcript of Herbein news conference, March 30, 1979, 11:00 a.m.

92. See "Report of the Public's Right to Information Task Force."

93. Watson deposition, pp. 73-76, 90-91.

94. Commission Hearing, May 19, 1979, p. 221.

95. Commission Hearing, May 19, 1979, p. 38. For a discussion of the mental health effects of the TMI accident, see "Report of the Behavioral Effects Task Group."

96. Commission Hearing, May 19, 1979, p. 127.

97. Henderson deposition, pp. 71-73; Commission Hearing, August 2, 1979, pp. 12-18. For full discussion on emergency planning and response, see "Technical Report on Emergency Preparedness and Response," "Report of the Public Health and Epidemiology Task Group," "Report of the Office of Chief Counsel on Emergency Preparedness," and "Report of the Office of Chief Counsel on Emergency Response." For dates and times in the following section, refer to the latter report.

98. Dieckamp deposition, pp. 129-136.

99. Denton deposition, pp. 101-102. For a complete discussion of the events concerning the hydrogen bubble, see "Report of the Office of Chief Counsel on Emergency Response." See also technical analysis of hydrogen production in technical staff analysis report on "Chemistry."

100. Knouse interview, pp. 71-73; transcript of Denton-Thornburgh news conference, March 30, 1979.

101. Waldman interview, pp. 68-69.

102. Watson deposition, pp. 52-57; Eidenberg deposition, p. 47-48.

103. Commission Hearing, August 2, 1979, pp. 194-195.

104. For a complete recount of the potassium iodide story, see "Report of the Public Health and Epidemiology Task Group" and "Report of the Office of Chief Counsel on Emergency Response."

105. Villforth deposition, pp. 33-35; "Chronology of Events at HEW Regarding TMI, 3/28/79 through 4/30/79."

106. For a complete discussion of the events concerning the hydrogen bubble, see "Report of the Office of Chief Counsel on Emergency Response." See also technical analysis of hydrogen production in technical staff analysis report on "Chemistry."

107. Mattson deposition, p. 184.

108. Id., p. 186.

109. Commission Hearing, August 22, 1979, pp. 294-296. See also Mattson deposition, pp. 178-180.

110. Mattson deposition, p. 179.

111. Id., pp. 190-191.

112. For a full discussion on this incident, see "Report of the Public's Right to Information Task Force."

113. Transcript of Denton-Thornburgh news conference, March 31, 1979, Part 1, p. 3.

114. For a more detailed discussion of HEW's activities during the accident, see "Report of the Office of Chief Counsel on Emergency Response" and "Report of the Public Health and Epidemiology Task Group."

115. Molloy deposition, pp. 81-100. See also Commission Hearing, August 2, 1979, p. 16.

116. Mattson deposition, p. 192.

117. Mattson interview, cassette 16, parts 5 and 6, pp. 34-35.

118. Id., cassette 17, parts 7 and 8, p. 4.

119. For a discussion on the NRC commissioners and their role in the management of the agency and during the emergency, see "Report of the Office of Chief Counsel on the Nuclear Regulatory Commission."

120. Transcript of Denton news conference, April 2, 1979. For a discussion of NRC public statements on the hydrogen bubble problems, see "Report of the Public's Right to Information Task Force."

121. Mattson interview, cassette 17, parts 7 and 8, p. 7. See also "Report of the Public's Right to Information Task Force."

122. For a complete recount of the potassium iodide story, see "Report of the Public Health and Epidemiology Task Group" and "Report of the Office of Chief Counsel on Emergency Response."

123. For discussion of Met Ed's recovery efforts, see section on TMI-2 recovery program in "Report of the Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers" and technical staff analysis report on "Recovery."

124. Molloy deposition, pp. 115-117. See also "Report of the Office of Chief Counsel on Emergency Response" and "Technical Staff Report on Emergency Preparedness and Response."

125. For a discussion of TMI-2's recovery program, see technical staff analysis report on "Recovery" and the TMI-2 recovery program section of "Report of the' Office of Chief Counsel on the Role of the Managing Utility and Its Suppliers."

GLOSSARY

Auxiliary building - A structure housing a variety of equipment and large tanks necessary for the operation of the reactor. These include make-up pumps, the make-up and waste gas decay tanks, and the reactor coolant hold-up tanks.

Babcock & Wilcox (B&W) - The company that designed and supplied the TMI-2 reactor and nuclear steam supply system.

Background radiation - Radiation arising from natural radioactive materials always present in the environment, including solar and cosmic radiation and radioactive elements in the upper atmosphere, the ground, building materials, and the human body.

Beta particles - High-energy electrons; a form of ionizing radiation that normally is stopped by the skin, or a very thin sheet of metal.

Bureau of Radiation Protection (BRP) - A division of Pennsylvania's Department of Environmental Resources. BRP is the state's lead agency in monitoring radiation releases from nuclear plants and advises the Pennsylvania Emergency Management Agency during radiological emergencies.

Burns and Roe - Architectural and engineering firm responsible for the design of TMI-2.

Candy cane - The section of pipe carrying water from the reactor to a steam generator.

Chain reaction - A self-sustaining reaction; occurs in nuclear fission when the number of neutrons released equals or exceeds the number of neutrons absorbed plus the neutrons which escape from the reactor.

Cladding - In a nuclear reactor, the metal shell of the fuel rod in which uranium oxide pellets are stacked.

Collective dose - The sum of the individual doses received by each member of a certain group or population. It is calculated by multiplying the average dose per person by the number of persons within a specific geographic area. Consequently, the collective dose is expressed in person-rems. For example, a thousand people each exposed to one rem would have a collective dose of 1,000 person-rems.

Condensate booster pumps - Three pumps located between the condensate polisher and the main feedwater pumps.

Condensate polisher - A device that removes dissolved minerals from the water of the feedwater system.

Condensatepumps - Three pumps in the feedwater system that pump water from the condensers to the condensate polishers.

Condensers - Devices that cool steam to water after the steam has passed through the turbine.

Containment building - The structure housing the nuclear reactor; intended to contain radioactive solids, gases, and water that might be released from the reactor vessel in an accident.

Control rod - A rod containing material that absorbs neutrons; used to control or halt nuclear fission in a reactor.

Core - The central part of a nuclear reactor that contains the fuel and produces the heat.

Critical - Term used to describe a nuclear reactor that is sustaining a chain reaction.

Curie - A unit of the intensity of radioactivity in a material. A curie is equal to 37 billion disintegrations each second.

Decay heat - Heat produced by the decay of radioactive particles; in a nuclear reactor this heat, resulting from materials left from the fission process, must be removed after reactor shutdown to prevent the core from overheating. See radioactive decay.

Design basis accident (DBA) - Hypothetical accidents evaluated during the safety review of nuclear power reactors. Plants are required to have safeguards that will ensure that radiation releases off-site will be within NRC limits should any of these accidents occur.

Emergency core cooling system (ECCS) - A backup system designed to supply cooling water to the **reactor core in a loss-of-coolant accident.**

Emergency feedwaterpumps - Backup pumps intended to supply feedwater to the steam generators should the feedwater system fail to supply water. Also called auxiliary feedwater pumps.

Feedwaterpumps - Two large pumps capable of supplying TMI-2's two steam generators with up to 15,500 gallons of water a minute.

GLOSSARY

Feedwater system - Water supply to the steam generators in a pressurized water reactor that is converted to steam to drive turbines; part of the secondary loop.

Fission - The splitting apart of a heavy atomic nucleus, into two or more parts when a neutron strikes the nucleus. The splitting releases a large amount of energy.

Fission products - Radioactive nuclei and elements formed by the fission of heavy elements.

Fuel damage - The failure of fuel rods and the release of the radioactive fission products trapped inside them. Fuel damage can occur without a melting of the reactor's uranium.

Fuel melt - The melting of some of the uranium oxide fuel inside a reactor.

Fuel rod - A tube containing fuel for a nuclear reactor.

Gamma rays - High-energy electromatic radiation; a form of ionizing radiation, of higher energy than X-rays, that penetrates very deep into body tissues.

General emergency - Declared by the utility when an incident at a nuclear power plant poses a potentially serious threat of radiation releases that could affect the general public.

General Public Utilities Corporation (GPU) - A utility holding company; parent corporation of the three companies that own TMI.

Genetic defects - Health defects inherited by a child from the mother and/or father.

Half-life - The time required for half of a given radioactive substance to decay.

Health physics - The practice of protecting humans and their environment from the possible hazards of radiation.

High pressure injection (HPI) - A pump system, capable of pumping up to about 1,000 gallons a minute into the reactor coolant system; part of the emergency core cooling system.

Iodine-131 - A radioactive form of iodine, with a half-life of 8.1 days, that can be absorbed by the human thyroid if inhaled or ingested and cause non-cancerous or cancerous growths.

Ionizing radiation - Radiation capable of displacing electrons from atoms; the process produces electrically charged atoms or ions. Forms include gamma rays, X-rays, and beta particles.

Isolation - Condition intended to contain radioactive materials released in a nuclear accident inside the containment building.

Krypton-85 - A radioactive noble gas, with a half-life of 10.7 years, that is not absorbed by body tissues and is soon eliminated by the body if inhaled or ingested.

Let-down system - A means of removing water from the reactor coolant system.

Loss-of-coolant accident (LOCA) - An accident involving a broken pipe, stuck-open valve, or other leak in the reactor coolant system that results in a loss of the water cooling the reactor core.

Make-up system - A means of adding water to the reactor coolant system during normal operation.

Make-up tank - A storage tank in the auxiliary building which provides water for the make-up pumps.

Meltdown - The melting of fuel in a nuclear reactor after the loss of coolant water. If a significant portion of the fuel should melt, the molten fuel could melt through the reactor vessel and release large quantities of radioactive materials into the containment building.

Metropolitan Edison Company (Met Ed) - Operator and part owner of the Three Mile Island nuclear power plant.

Millirem - 1 one-thousandth of a rem; see rem.

Natural cooling - The circulation of water without pumping by heating water in the core and cooling it in the steam generator.

Neutron - An uncharged particle found in the nucleus of every atom heavier than ordinary hydrogen; neutrons sustain the fission chain reaction in nuclear reactors.

Noble gases - Inert gases that do not react chemically and are not absorbed by body tissues, although they may enter the blood if inhaled into the lungs. These gases include helium, neon, krypton, xenon, and radon.

Nuclear Regulatory Commission (NRC) - U.S. agency responsible for the licensing and regulation of commercial, test, and research nuclear reactors.

Nucleus - The central core of an atom.

Pennsylvania Emergency Management Agency (PEMA) - Agency responsible for the state's response to natural and human-made disasters.

Person-rems - See collective dose.

"Poisons" - Materials that strongly absorb neutrons; used to control or stop the fission reaction in a nuclear reactor.

Pilot-operated relief valve (PORV) - A valve on the TMI-2 pressurizer, designed to open when steam pressure reaches 2,255 pounds per square inch.

Potassium iodide - A chemical that readily enters the thyroid gland when ingested. If taken in a sufficient quantity prior to exposure to radioactive iodine, it can prevent the thyroid from absorbing any of the potentially harmful radioactive iodine-131.

Pressure vessel - See reactor vessel.

Pressurizer - A tank that maintains the proper reactor coolant pressure in a pressurized water reactor.

Pressurized water reactor - A nuclear reactor system in which reactor coolant water is kept under high pressure to keep it from boiling into steam.

Primary system - See reactor coolant system.

Radioactive decay - The spontaneous process by which an unstable radioactive nucleus releases energy or particles to become stable.

Radioactivity - The spontaneous decay of an unstable atom. During the decay process, ionizing radiation is usually given off.

Radiolysis - The breaking apart of a molecule by radiation, such as the splitting of water into hydrogen and oxygen.

Reactor (nuclear) - A device in which a fission chain reaction can be initiated, maintained, and controlled.

Reactor coolant pump - One of four large pumps used to circulate the water cooling the core of the TMI-2 reactor.

Reactor coolant system - Water that cools the reactor core and carries away heat. Also called the primary loop.

Reactor vessel - The steel tank containing the reactor core; also called the pressure vessel.

Rem - A standard unit of radiation dose. Frequently radiation dose is measured in millirems for low-level radiation; 1,000 millirems equal one rem.

Respirator - A breathing mask that filters the air to protect against the inhalation of radioactive materials.

Safety-related - The NRC employes several broad definitions for this concept. By one, safety-related items are "structures, systems and components that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public." However, the NRC has no specific list of safety-related items. The licensee designates what in its plant is considered safety-related. If the NRC disagrees, the question is negotiated. Safety-related items receive closer quality control and assurance, maintenance, and NRC inspection.

Saturation temperature - The temperature at which water at a given pressure will boil; the saturation point of water at sea-level is 212° F.

Scram - The rapid shutdown of a nuclear reactor, by dropping control rods into the core to halt fission.

Secondary system - See feedwater system.

Site emergency - Declared by the utility when an incident at a nuclear power plant threatens the uncontrolled release of radioactivity into the immediate area of the plant.

Solid system - A condition in which the entire reactor coolant system, including the pressurizer, is filled with water.

Steam generator - A heat exchanger in which reactor coolant water flowing through tubes heats the feedwater to produce steam.

Steam table - A chart used to determine the temperature at which water will boil at a given pressure.

Teratogenesis - The process of the development of gross abnormalities in the developing unborn child; these abnormalities or birth defects are not inherited.

Thermoluminescent dosimeter (TLD) - A device to measure nuclear radiation.

TMI - Three Mile Island; site of two nuclear power reactors operated by Metropolitan Edison Company.

Transient - An abnormal condition or event in a nuclear power system.

Trip - A sudden shutdown of a piece of machinery.

Turbine building - A structure housing the steam turbine, generator, and much of the feedwater system.

Uranium Oxide (UO) - A chemical compound containing uranium and oxygen that is used as a fuel in nuclear reactors.

Waste gas decay tank - One of two auxiliary building tanks in which radioactive gases removed from the reactor coolant are stored.

Xenon-133 - A radioactive noble gas, with a half-life of 5.3 days, that is not absorbed by body tissues and is soon eliminated by the body if inhaled or ingested.

Zircaloy-4 - A zirconium alloy from which fuel rod cladding is made.