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Three Mile Island Nuclear Accident

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Description

The accident at the Three Mile Island Unit 2 (TMI-2) nuclear power plant in Pennsylvania on March 28, 1979 was one of the most serious in the history of the U.S. nuclear industry. It not only brought to light the hazards associated with nuclear power, but also forced the industry to take a closer look at the operating procedures used at the time. What makes the TMI-2 accident such an interesting case study is the series of events which led up to the partial meltdown of the reactor core.

Body

Detailed Description of Accident

At 36 seconds past 4:00 a.m. on the 28th of March, 1979 the first of a series of pumps feeding water to the steam generators at the Three Mile Island nuclear plant stopped functioning.

It was later determined that this was caused by maintenance work being done on the Number 7 Polisher at the time. The steam produced by the reactor not only runs the generators to produce electricity but also serves to cool down the reactor core, reducing the risk of a meltdown. When the flow of the water stopped the

temperature inside the reactor core increased. This caused the water inside the reactor to expand, increasing the pressure inside the pressurizer to 2200 psi, 100 psi more than the normal. As designed the increase in pressure caused the Pilot Operated Relief Valve to open (PORV) draining the steam and water from the reactor core into a tank on the floor.

At this point the three emergency feedwater pumps started. An operator noticed that they were running, but he did not notice that the valves on the emergency feedwater lines were closed. The panel in the control room had lights to indicate that the valves were closed, one of the lights was covered by a yellow maintenance tag, while the operator did not notice the other light.

Despite the opening of the PORV the pressure continued to rise, 9 seconds into the accident the control rods automatically lowered as designed to halt the fission reaction. This halted the fission reaction but the latent heat of the radioactive material continued to heat the water. Even though this heat was a fraction of what is normally produced during the fission reaction, it was enough to potentially overheat the core. 13 seconds into the accident the PORV should have closed since the pressure in the reactor had dropped. The light indicating that the PORV was energized (i.e. open) shut off, leading the operators to assume that the PORV had now closed. In reality the PORV was stuck open and steam and water was escaping from the reactor. This is known as a Loss of Coolant Accident (LOCA).

In the first 100 minutes of the accident almost 32,000 gallons of water, or one third of the reactor's capacity escaped through the PORV. The accident at TMI could have been contained had either the PORV shut at this point, or the operators noticed that the valve was stuck open. During the initial stages of the accident Edward Fredrick and Craig Faust, the Control Room Operators were present in the control room. One of the factors which added to the severity of the accident at TMI was the inadequate training of the employees at the facility. The training was the responsibility of Met Ed and Babcock and Wilcox.

Over 100 alarms went off in the control room during the first few minutes of the accident. This added to the confusion without providing any useful information to the operators. Both Faust and Fredrick dealt with the alarms to the best of their ability based on the training they had received.

2 Minutes into the accident the pressure of the water in the reactor dropped sharply which caused the Emergency Injection Water (EIW) to be automatically activated. This sent about 1000 gallons of water per minute into the reactor coolant system.

The falling pressure coupled with constant reactor coolant temperature should have alerted the operators to the LOCA. Instead, fearing that the core would have too much water, Operator Fredrick turned off one of the EIW pumps, reducing the flow of water into the core to less than 100 gallons per minute.

8 Minutes into the accident it was discovered that the emergency feed water was not reaching the core because of the closed valves. Operator Faust proceeded to open these valves, allowing water to rush into the steam generators. It was later discovered that these valves were closed two days earlier during a routine test of the pumps. At 4:11 a.m. an alarm signaled high water in the containment building. This is the building where all the water draining from the core through the PORV is stored. In itself this alarm should have been a clear indication of a leak in the coolant system. When Fredrick was informed of this he recommended that the sump pumps draining water to the containment building be shut off.

By about 6:15 a.m., roughly 2 hours and 15 minutes into the accident, the level of water in the reactor had dropped below the level of the core. Unknown to the operators the core is now uncovered. It is essential that the core remain covered at all times to prevent it from over heating. Once the core over heats the zirconium alloy of the fuel rod cladding reacts with the steam to produce hydrogen gas. This is what happened in the TMI reactor, not only is the hydrogen produced flammable, but the diminishment of the fuel rod cladding increases the risk of radioactive contamination.

The water continued to leak out of the PORV until 6:22 a.m. when Leland Rogers, the Babcock & Wilcox site representative at TMI asked the operators if they had shut the block valve which is the backup valve to the PORV. At this point the PORV was shut after having remained open for 2 hours and 22 minutes. It is still unclear whether Rogers was responsible for the valve being shut. Edward Fredrick testified that the valve was closed at the suggestion of a shift supervisor coming onto the next shift. Based on increasing radiation levels, at around 7:00 a.m. a site emergency was declared, indicating the threat of release of radioactivity into the surrounding environment. As the radiation levels continued to increase, the staff of TMI-2 was contacting local law enforcement and local energy providers. At 7:24 a general

emergency was declared at the TMI-2 site and the site began to be evacuated. By 11:00 a.m. all nonessential personnel were ordered off of the island, and the remaining technicians were forced to wear face masks to block any air borne radioactive particles. At 1:50 p.m. the operators in the control room heard what they described as a loud "thud." While they dismissed the sound as well as the pressure spike indicated by their instruments as a malfunction, the thud was actually a hydrogen explosion inside the containment building. It is another several hours before the partially melted core is brought to a controllable temperature using water from the primary loops.

Immediate Reaction to the Accident

Shortly after the accident occurred, an incorrect reading reported traces of radioactive iodine-131 in the Goldsboror area. While the reading caused an immediate need for concern, the readings were later found to be erroneous. A build up in radioactive iodine in human's thyroids from inhaling radioactive particles or drinking contaminated milk remained the primary concern of the top officials including Governor William Scranton III. The Governor was incorrectly informed that the release of steam represented the primary concern to the surrounding environment, despite the fact that there was no indication that radioactive steam had escaped from the reactor core or the pumps feeding the core.

The evening of the accident, mayor of Goldsboro, Ken Meyers, met with his council members to discuss the possibility of an evacuation. The council members proceeded to go door to door through the town providing families with whatever information they could, mostly consisting of information they themselves had heard from news reports, as well as explaining the evacuation procedure should Governor Scranton declare a state of emergency.

Following the accident, numerous tests were conducted in attempts to conclude what if any effect increased radiation would have on the health of human, animal and plant life in the surrounding area. Through these studies, it was revealed that the majority of radioactive material had been contained by the core. Despite the immediate concern, however, a later government report indicated that there would likely be one additional death as a result of cancer due to increased radiation levels in the surrounding area in a 30 year period.

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The Cleanup Operation

During the cleanup operations at the Three Mile Island nuclear reactor there were issues of ethical misconduct on the part of both organizations and individuals that occurred. Professor Stephen Unger of Columbia University has discussed one such example in his book "Controlling Technology."

Background Information

In order to further discuss these issues it is important to understand the relationship between the organizations and individuals involved.

The key individuals involved were:

Laurence P. King

Director of Site Operations, General Public Utilities

Richard D. Parks

Senior Startup Engineer, Bechtel Northern Corporation

Edwin H. Gischel

Plant Engineering Director, General Public Utilities

The task for cleaning up was given to an organization involving both General Public Utilities (GPU) and the Bechtel Northern Corporation. At the same time the Nuclear Regulatory Commission (NRC) was present on site to monitor the cleanup operations.

Laurence P. King was responsible for the site cleanup operations on the GPU side.

Richard D. Parks was employed by Bechtel as a senior startup engineer and seconded as an operations engineer to the Site Operations Department under Laurence P. King. His duties involved liaison with the NRC and ensuring compliance with licensing requirements. In addition he served as an alternate startup and test manager for the plant.

Edwin H. Gischel was the Plant Engineering Director and worked under Laurence P. King.

One of the issues later brought up was that the NRC worked too closely with the organizations directly involved with the clean up of the reactor. This tended to take away from the NRC's ability to regulate the safety and effectiveness of the operations. There were times when proposals would be unofficially approved by the NRC before the other organizations were able to fully develop or approve them. This, combined with the perception that the NRC was more concerned with expediting the cleanup process rather than ensuring it was done correctly encouraged people to cut corners.

The Issue

In any industrial operation overhead cranes used for lifting heavy equipment play an important role. The polar crane used during the cleanup of TMI-2 had been damaged during the original accident. During the repairing of the crane various parts that were damaged had been substituted with replacements that were not exactly the same as the originals. In addition the crane had been modified to perform duties that exceeded the original manufacturer specifications. Due to the nature of the cleanup operation the changes made posed a hazard to not only the workers on site but also to people in the surrounding areas.

King received reports from both Parks and Gischel which stated concerns over the use of the Polar Crane. Prior to that King had already experienced difficulties with the cleanup operations. He felt that established engineering procedures were not being followed by other high level managers, particularly Bechtel people.

Based on what he had seen and the reports he received King decided that the crane should be carefully tested before being put into service. Top management at GPUN and Bechtel did not agree with King's assessment of the situation and felt that he was being overly cautious.

In reaction to the Gischel's report, King's superior ordered King to immediately fire Gischel. King refused and defended Gischel's position. At this point GPU's tactics turned nasty.

After suffering a stroke a year before, Gischel had seen a psychologist working under GPU. At the time, the psychologist suggested Gischel take a neuropsychological evaluation, but Gischel refused to take the test. Almost immediately following the release of the report, he again received a letter suggesting he take the exam. Robert Arnold, the president of GPU Nuclear, continued pressuring Gischel and in a clear violation of the doctor-patient relationship disclosed that he had knowledge of the topics of Gischel's meetings with the GPU employed psychologist. After a letter insisting Gischel take the exam from the board chairman of GPU, Gischel sent a sworn affidavit to Arnold explaining his take on the TMI cleanup operations and the events that followed. Gischel requested that Arnold forward the affidavit to the NRC which he did, but on July 1 after Gischel still refused to take the neuropsychological exam he was transferred to a different subsidiary of GPU.

Richard Parks also filed a sworn affidavit and submitted it to the NRC, and a harassment complaint filed against GPU Nuclear. Parks's complaint was filed on the grounds that a manager told him Parks's superiors were considering transferring him off site, he was demoted from his position as alternate startup and test manager, and was informed of a false rumor that his ex-wife (who was actually deceased) was trying to dig up dirt on Parks to get custody of their two children. The day after he filed his complaint Parks was suspended with pay on the grounds that his continued working would subject him to continued harassment from his coworkers.

In February of 1983 GPU Nuclear accused King of hiring employees away from GPUN for his own firm, Quiltec. Accused of a conflict of interest, King was suspended and locked out of his office while he claims that documents he wrote concerning the cleanup process were destroyed. King's secretary, Joyce Wagner, was also forced into suspension and within a month both King and Wagner had been fired.

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The Accident's Impact

The numerous ethical questions surrounding the TMI-2 cleanup procedure might suggest that nothing positive could have resulted from the incident. Beyond the questionable behavior on the part of the companies responsible for the cleanup, radiation presented a major problem for the cleanup crews as did algae that not only grew, but thrived in the contaminated water. There were important scientific as well as sociological issues that resulted from the accident. The following is based on Matthew L. Wald's article "After the Meltdown, Lessons from a Cleanup" that appeared in the April 24, 1990 edition of the *New York Times*

What the cleanup effort did prove was that, despite requiring 400 workers, over 4 1/2 years, and 970 million dollars, the cleanup of a nuclear disaster area is possible. Unlike the Soviet approach to the cleanup at the Chernobyl disaster site, where the reactor was encased in an enormous concrete structure, the cleanup of the reactor site and especially the reactor vessel at TMI-2 provided many answers to questions surrounding the accident and even provided some hints as to the nature of exactly how stable reactor vessels are.

During the cleanup process the team learned that despite the 51% meltdown of the reactor core, that the reactor vessel was relatively undamaged. This indicated two separate points. First that it was far easier to have a meltdown to the core than expected, but secondly that at least in this case, the reactor vessel was able to withstand temperature much higher than anticipated.

Beyond scientific impact, however, remains the impact that the accident had on the public. Many analysts in the nuclear industry believe that the incident at TMI-2 has meant the nuclear industry has only one more chance. Analysts feel that another nuclear accident on the scale of TMI-2 will result in public outcry for the closing of the other nuclear plants around the nation.

Timeline of Events Occurring During the Three Mile Island Disaster

Elapsed Time	Event
00:00:00	<p>Pumps feeding water to the secondary loop shut down.</p> <p>This was the first of two independent system failures that led to the near meltdown of the Three Mile Island Nuclear Reactor.</p>
00:00:01	<p>Alarm sounds within the TMI control room.</p> <p>At the time this alarm is disregarded by the operators.</p>
00:00:02	<p>Water pressure and temperature in the reactor core rise.</p> <p>The failure of the secondary loop pump has stopped the transfer of heat from the Primary Loop to the secondary loop. The rise in temperature and pressure is considered to be part of the normal plant operations, and hence ignored.</p>
00:00:03	<p>Pressure Relief valve (PORV) automatically opens</p> <p>When the pressure of steam in the reactor core rises above safe limits, the pressure relief valve is designed to automatically open, releasing the excess steam to a containment tank.</p>
00:00:04	<p>Backup pumps for the secondary loop water system automatically turn on.</p> <p>Four seconds into the accident the secondary loop water pumps are automatically turned on. This is indicated to the operators by the presence of lights on the control panel. The operators are not aware that the pumps have been disconnected and are not functioning.</p>

00:00:09	<p>Boron and Silver control rods are lowered into the reactor. PORV light goes out, indicating valve is closed.</p> <p>Lowering of the control rods into the reactor core slows down the rate of the reaction. The effect of which is also a reduction in the heat produced by the reactor. When the PORV light goes out the operators incorrectly assume that the valve is closed. In reality the valve is not only open but is also releasing steam and water from the core. This is now a LOCA (Loss of Coolant Accident)</p>
00:02:00	<p>Emergency Injection Water (EIW) is automatically activated.</p> <p>The EIW is a safety device that causes water to flow into the reactor core. It is designed to ensure that when there is a LOCA the water in the core remains at a safe level. In the past the EIW system has turned itself on when there has been no leak so the operators are not unduly concerned by this.</p>
00:04:30	<p>Operators observe that the water level in the Primary System is rising while the pressure is decreasing.</p> <p>When they observe that the water level in the core is rising the operators shut off the EIW system.</p>
00:04:30	<p>Water level in the core still appears to be rising.</p> <p>In actuality the water level in the core is dropping and turning off the EIW increases the amount of steam being produced by the reactor core. The combination of steam and water is still being released through the PORV.</p>

00:08:00	<p>Operator notices that the valves for the secondary loop backup pumps are off.</p> <p>8 minutes into the accident the closed valve is noticed by an operator. Once he turns the valves back on the Secondary Water loop is functioning correctly.</p>
00:45:00	<p>Water level in primary loop continues to drop.</p> <p>At this point in the accident the operators still do not suspect a LOCA. The instrument checking the radiation has not registered an alarm, and the gauges in the control room are wrongly indicating that the water level is up.</p>
01:20:00	<p>Primary loop pumps start to shake violently.</p> <p>Steam produced by the lack of cooling water in the core passes through the primary loop pumps and causes them to shake.</p> <p>Assuming they are not functioning correctly the operators turn off two of the four pumps</p> <p>.</p>
01:20:00	<p>Remaining two pumps in the primary loop turn off.</p> <p>The automatic shut down of the two remaining pumps in the primary loop causes the water within the nuclear core to stop circulating. This in turn causes the heated core to convert more water into steam, further reducing the transfer of heat away from the core.</p>

02:15:00	<p>Water level drops below the top of the core.</p> <p>Once the top of the core is exposed the steam is converted to super heated steam. This reacts with the control rods and produces hydrogen and other radioactive gases.</p>
02:15:00	<p>Hydrogen gas is released through PORV.</p> <p>Since the Pilot Operated Relief Valve is still in the open position it allows the hydrogen gas produced to be released along with the steam.</p>
02:20:00	<p>Operator from next shift arrives and closes PORV backup valve.</p>
02:20:30	<p>Operators receive first indication that the radiation levels are up.</p>
02:45:00	<p>Radiation alarm sounds and a site emergency is declared.</p> <p>At this point half the core is uncovered and the radiation level of the water in the primary loop is 350 times its normal level.</p>
03:00:00	<p>Due to higher radiation levels a General Emergency is declared.</p> <p>There is still confusion as to whether the core is uncovered or not. There are some that feel the temperature readings may be erroneous.</p>
07:30:00	<p>Operators pump water into the primary loop and open the PORV backup valve to lower the pressure.</p>

09:00:00	<p>Hydrogen within the containment structure explodes.</p> <p>The explosion is recorded by the instruments in the control room. It is dismissed as just being a spike caused by an electrical malfunction. The sound of the explosion heard is thought by some to be a ventilator damper.</p>
15:00:00	<p>Primary loop pumps are turned on.</p> <p>By now a large portion of the core has melted and there is still hydrogen present in the primary loop. Water from the primary loop pumps is circulated and the core temperature is finally brought under control.</p>

Nuclear Reactor Technical Information

It is important to understand the basics of how a nuclear reactor produces electricity and what the basic components of the reactor at Three Mile Island were. Three Mile Island was the home to two nuclear plants, TMI-1 and TMI-2. Their combined power generating capacity was 1,700 megawatts or enough electricity to supply 300,000 homes. In a nutshell, nuclear power plants generate electricity by using steam turbines. The function of the nuclear fuel is to heat water and convert it to steam. Now in theory this sounds quite simple, but the hazards associated with nuclear fuels add to the complications. A nuclear reactor such as TMI-2 can be divided into various sub-systems.

In order to understand the accident at TMI it is essential that we have a rudimentary understanding of how these systems function.

THE NUCLEAR REACTOR

A nuclear reactor generates heat by harnessing atomic energy. The core of an atom, which is also called the nucleus, can be split by bombarding it with neutrons. When a free neutron strikes the core it splits the atom into two smaller atom fragments, giving off energy in the form of kinetic energy of the fragments, plus 2 or three neutrons -and likely some gamma rays-. One of the neutrons produced by this reaction strikes another atom, which in turn produces more energy and more neutrons. This chain reaction continues from one atom to another producing nuclear fission energy. Thanks to Elaine Walker for providing feedback and some of the information contained in this paragraph..

The TMI-2 Reactor Core held 100 tons of uranium to fuel the nuclear reaction. This was in the form of cylindrical uranium oxide pellets that were one inch tall and roughly one half inch wide. These pellets were stacked inside 12-foot long fuel rods made of a zirconium alloy (Zircaloy-4). The entire reactor consisted of 36,816 such fuel rods along with 69 control rods, 52 instrument tubes and spaces between them for the cooling water to flow.

Control rods are used to control the amount of power produced by the reactor, or to completely halt the reaction in the case of an emergency. The control rods are able to control the rate of nuclear fission taking place by absorbing a portion of the free neutrons produced. The rate varies depending on the number of rods and the length of the rod inserted into the core of the reactor. TMI-2 used control rods made of 80% Silver, 15% indium and 5% cadmium.

Control rods are designed such that in the event of an emergency the magnetic clamps holding them release the rods into the core of the reactor thus completely halting the reaction.

The Instrument Tubes contain instruments used to measure such things as the temperature within the reactor.

WATER SYSTEMS

There are three basic closed loop Water Systems in a nuclear power plant such as the one at TMI.

The first water system is the Primary Loop or the Reactor Coolant System. This is a closed loop system that circulates water through the nuclear core and serves two purposes. Firstly, by coming in contact with the hot fuel rods the water is heated. At the same time the water flowing through the core cools down the fuel rods preventing them from melting. It is important that the water coming in contact with the reactor core remain in liquid form so that it can effectively cool the rods. In order to prevent the water from turning into steam it is pressurized to about 2,155 psi. In the event of an accident either an increase in temperature or a decrease in pressure can convert the heated water to steam, this is undesirable but not dangerous because the steam too can help cool the reactor core.

Once the steam from the Feedwater System has driven the turbines it goes to the condenser where it is cooled and converted back to water. The final water system is the Condenser Water that is cooled in the cooling towers. This is the water used to cool the steam from the turbines and is also a closed loop water system. This ensures that the radioactive water from the reactor cannot contaminate the water in the cooling towers or the water vapor that is released from the cooling towers to the atmosphere.

Under normal operating conditions the primary loop is the only system which contains traces of radiation.

STEAM GENERATORS

Heated water from the reactor goes to the Steam Generator where it is passed through corrosion resistant tubes. At the same time water from the Secondary Loop or Feedwater System is passed through the steam generator around the tubes containing hot water from the reactor. This converts the Secondary Loop water into steam and also cools down the reactor coolant water. It is important to note that at no point does water from the two separate systems mix with each other.

STEAM TURBINE

The steam is then sent to the Steam Turbines where it runs the electricity-producing generator while the relatively cooler water of the Reactor Coolant System is sent

back into the reactor core to pick up more heat and repeat the whole cycle.

AUXILIARIES

The Pressurizer ensures that the reactor coolant water is kept at the correct pressure. If for some reason the water pressure increases above safe levels the Pilot Operated Relief Valve (PORV) is supposed to open, thus relieving excess pressure by releasing water/steam to the drain tank. While this solves the immediate problem and prevents the reactor vessel from getting damaged, it reduces the level of water in nuclear core.

A reduction in the reactor core water level would lead to the core being uncovered. This is undesirable because it would allow the core temperature to increase beyond safe levels. If the core temperature were to reach around 2,200 degrees Fahrenheit the water would begin to react with the cladding producing hydrogen. This could potentially explode. If the temperature were to reach 5,200 degrees Fahrenheit the uranium could potentially melt, releasing far more radioactive materials into the surroundings.

Rights

Use of Materials on the OEC

Resource Type

Case Study / Scenario

Topics

Public Health and Safety

Social Responsibility

Catastrophes, Hazards, Disasters

Risk

Discipline(s)

Engineering

Nuclear Engineering

Authoring Institution

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