



Semarak International Journal of Chemical Process Engineering

Journal homepage:
<https://semarakilmu.my/index.php/sijcpe/index>
ISSN: 3083-8916



Preventing Nuclear Accidents: The Need for Public Awareness, Safety Protocols and Environmental Justice

Nurul Habibah Nor Hassan¹, Nurmira Batrisyia Mohd Radzuan¹, Mohammad Syahmi Aladin¹, Siti Amira Othman^{1,*}

¹ Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, 84600, Pagoh, Johor, Malaysia

ARTICLE INFO

Article history:

Received 27 March 2025

Received in revised form 21 April 2025

Accepted 19 May 2025

Available online 20 June 2025

Keywords:

Nuclear accidents; environmental;
Samut Prakan; Chernobyl; Church Rock
uranium

ABSTRACT

The Samut Prakan Radiation Accident highlights the critical need for better public awareness regarding radioactive materials. This incident, where individuals unknowingly interacted with a dangerous radiation source, underscores a significant gap in knowledge about the risks posed by such materials. It serves as a stark reminder of the importance of safety protocols and education in preventing such tragedies. A lack of public education on radioactive materials and insufficient awareness of the potential hazards led to the Samut Prakan accident. Additionally, the absence of universally recognized safety symbols and warning labels on devices containing radioactive substances contributed to this tragic event. The case further reveals the lack of preparation among emergency responders and those who handle radioactive materials, which exacerbated the potential for harm. From the Samut Prakan accident and similar incidents, such as the Chernobyl disaster, we learn the critical need for safer designs, better safety training, and more robust regulatory frameworks in handling nuclear materials. Public education campaigns, along with clear and recognizable safety symbols, could significantly reduce the risk of such accidents. Furthermore, ensuring that emergency responders are well-trained and prepared for radiation-related incidents is essential to preventing public health crises. The Chernobyl disaster also highlights the importance of having clear emergency plans and long-term support for affected communities. Lastly, the Church Rock uranium spill exposes the intersection of environmental injustice and nuclear policy, particularly in its disproportionate impact on Indigenous communities, calling for more comprehensive efforts toward environmental restoration and justice. The lessons from the Samut Prakan Radiation Accident, Chernobyl, and the Church Rock spill emphasize the importance of safety, education, and environmental justice in nuclear energy practices. By addressing these issues through improved public awareness, stronger safety protocols, and a commitment to restorative justice for impacted communities can prevent similar tragedies and work towards a safer and more equitable future in the handling of nuclear materials.

* Corresponding author.

E-mail address: sitiamira@uthm.edu.my

<https://doi.org/10.37934/sijcpe.3.1.3751>

1. Samut Prakan Radiation Accident

1.1 Introduction

The International Atomic Energy Agency (IAEA) published *The Radiological Accident in Samut Prakan* in 2002, which is a full analysis of the Samut Prakan radiation accident, including its causes, medical consequences, emergency response, and lessons learned. Radioactive materials, such as cobalt-60, have improved industries including medical, research, and industry. These materials allow treatments varying from cancer therapy to industrial radiography, exhibiting wide utility in both healthcare and technology applications. However, the advantages of radioactive sources come with equally serious dangers. Mishandling high-energy radioactive materials can result in severe gamma radiation, threatening persons and communities' health. To avoid accidents, rigid regulations are in place nationwide that guide the safe use, storage, and disposal of these materials. Nonetheless, these events continue to occur as a result of regulatory breaches, insufficient training, and a lack of public awareness [1].

In January 2000, a particular tragedy occurred in Samut Prakan, a province near Bangkok, Thailand. This incident involves a cobalt-60 radiation device originally used in cancer treatment that was incorrectly maintained and subsequently abandoned. The gadget, which included a high-intensity cobalt-60 source, was left unsecured after being withdrawn from duty and landed up in a junkyard. Workers at the junkyard, uninformed of the dangers, disassembled the gadget with simple tools, exposing themselves and others to deadly levels of radiation. This resulted in severe cases of radiation sickness, including burns, hair loss, nausea, and, in rare cases, death. Three people died as a result of acute radiation sickness, while others suffered long-term health consequences. The tragedy was only found when medical professionals detected strange symptoms in several patients and properly identified the possibility of radiation exposure.

The purpose of this research is to investigate the Samut Prakan radiation accident in depth, analyzing it from many perspectives to more fully understand both the primary causes and the larger consequences. The investigation will help to shed understanding of the issues of radiation safety, especially under situations when radioactive materials are no longer in active use. This paper intends to add to the current discussion about improving radiation safety standards by evaluating the sequence of events, examining the lessons learned, and recommending preventive actions. The Samut Prakan accident teaches important lessons to regulatory bodies, medical professionals, and companies that manage radioactive materials. Strengthening policies, raising public awareness, and improving emergency response skills are all critical steps toward preventing future radioactive disasters and protecting public health [2].

1.2 Chronology of Accident

The Samut Prakan radiation tragedy, which occurred in Thailand in early 2000, is a major example in recognizing the dangers of mishandled radioactive materials. The tragedy included a discontinued cobalt-60 teletherapy device that had been left unattended in a storage area. Because the device was improperly disposed of and destroyed by unsuspecting personnel, the resulting radiation exposure had serious consequences for health, including fatalities. This chronology describes the important events that occurred both before and during the exposure incident. In the latter part of 1999, a Bangkok-based company that owned many teletherapy units, including the cobalt-60 device involved in the tragedy, relocated the devices from a licensed facility to an unsafe parking lot. The company failed to notify the Thai Office of Atomic Energy for Peace (OAEP), and the devices were kept without sufficient safety measures or labeling. The storage lot, which was walled but easily accessible, posed a significant concern because it was located in a highly residential location with frequent pedestrian activity [3].

This accident started on January 24, 2000, when a group of local scrap metal collectors discovered the abandoned cobalt-60 device in the parking lot and began disassembling it, completely unaware of the dangers. The device contained radiation warning symbols, but the scrap collectors, unable to detect or understand the warnings, continued to disassemble it with simple tools. They brought it to one of the workers' homes (Patient 1) for further disassembling before leaving it in an open location near residential areas. Continued on February 1, 2000, after several unsuccessful attempts to dismantle the device, two workers brought it to a junkyard in

Samut Prakan. An employee at the junkyard used an oxyacetylene torch to cut apart the gadget, resulting in high radiation. During this process, he noticed a strange "yellow smoke" and experienced immediate discomfort, including itching and drowsiness after touching the device's internal components. Ignoring these symptoms, the workers continued to dismantle the equipment, not aware that they had exposed themselves to a hazardous source of radiation.

Around February 3-4, 2000, many workers began to show signs of acute radiation illness, such as nausea, vomiting, headaches, and skin burns. Because these days coincided with the Chinese New Year break, the majority of those affected stayed at home, suffering from decreasing conditions. However, neither the workers nor their fellow citizens suspected being exposed to radiation as the reason. On February 15, 2000, patient 1, whose condition was declining drastically, sought medical assistance at Samut Prakan Hospital. He showed serious signs of radiation sickness, including skin burns on his hands, vomiting, and hair loss. Additional patients quickly reported identical symptoms, leading the hospital's clinicians to suspect exposure to an unsecured radioactive source. Recognizing the seriousness of the issue, hospital workers contacted the OAEP on February 18 [4].

Subsequently, on February 18, 2000, the OAEP responded by sending radiation protection workers to the Samut Prakan area. Upon arrival, the authorities conducted radiation surveys, which revealed elevated levels near the junkyard. Further inquiry took them to the source within the junkyard, where they discovered a strong gamma radiation field. The authorities blocked off the area and called in an emergency response to properly retrieve the source. Thus, on February 20, 2000, the OAEP with the cooperation of local authorities, successfully recovered the cobalt-60 source from the junkyard. The reaction team used advanced machinery to isolate the source, store it in a shielded container, and transfer it to a safe storage facility. Radiation levels in the junkyard and nearby regions were then tested to determine that background levels had returned to normal, indicating that the site was safe for people.

As the impact, the accident had serious implications for health for all involved. Ten people were exposed to high levels of radiation, three of them died as a result of radiation-related illnesses within two months. This heartbroken event exposed fundamental flaws in regulatory enforcement, public education about radiation concerns, and emergency preparedness. The incident highlighted the critical need for stronger radiation safety protocols, particularly those regulating the disposal and secure storage of unused radioactive materials [5].

1.3 Lesson Learned from Accident

The Samut Prakan radiation tragedy reveals insight into shortcomings in radiation safety standards, regulatory control, and public awareness. A detailed examination of the event reveals numerous crucial lessons, each of which highlights areas in which changes could prevent similar incidents in the future.

1.3.1 Importance of secure storage and disposal of radioactive sources

The Samut Prakan radiation accident illustrates the importance of secure storage practices for sealed radioactive sources, which are widely used in fields like medicine, industry, and agriculture. These sources contain radioactive material permanently sealed in a capsule, designed to prevent leakage under normal conditions. Typically small in size, ranging from a few millimeters to several centimeters, these sources are often installed in specialized devices to safely direct radiation for uses like medical treatments or industrial inspections [6].

One of the main causes of the accident was the improper storage of a high-activity cobalt-60 source. After being removed from service, the cobalt-60 teletherapy unit was transferred from a licensed facility to an unprotected parking lot without prior notification or consent from the Office of Atomic Energy for Peace (OAEP). This inadequate management allowed inexperienced individuals to access and disassemble the device, resulting in significant radiation exposure. The incident emphasizes the importance of strict rules for the safe storage and management of radioactive materials, especially once they are no longer in active use. Radiation safety best practices include ongoing surveillance and secure confinement of radioactive sources until they are disposed of or transferred to designated facilities.

1.3.2 Enhancing public awareness and worker safety training

Another important lesson from this incident is the significance of promoting public awareness and educating those who could potentially come into touch with radioactive materials, such as scrap metal workers. The workers who handled the cobalt-60 equipment were unaware of the risks related with the radiation symbol displayed on the teletherapy unit, and they were not trained to recognize the potential hazard. As a result, they unintentionally exposed themselves to dangerous radiation levels. This lack of understanding resulted in several deaths and serious radiation-related diseases among those involved. Public awareness campaigns and training programs are essential elements for radiation safety. Educating workers in scrap metal industries and other potentially hazardous environments can help them spot radioactive symbols, understand fundamental radiation concerns, and be aware when to reach out to authorities [7].

1.3.3 Improving emergency response and preparedness

The length of time taken in recognizing and responding to the Samut Prakan incident emphasizes the importance of a well-prepared and quick emergency response system for radioactive accidents. The exposed individuals quickly displayed symptoms of radiation sickness, but the reason took weeks to be recognized. A swift reaction could have shortened the period of radiation exposure and lowered the health risks for individuals impacted. The situation highlighted the importance of training healthcare providers to recognize radiation-related illnesses, particularly in places where radioactive sources are available for use.

Improving emergency response skills requires cooperation among radiation protection authorities, healthcare specialists, and local emergency responders [8]. This should include specific training in detecting radiation and waste control, as well as immediate communication protocols that allow hospitals to notify radiation authorities as soon as signs of radiation exposure are discovered.

Hence, the lessons acquired from the Samut Prakan accident act as an urgent reminder of the importance of strict safety measures, governmental supervision, and the general awareness of radioactive materials. The lessons from this incident highlight the importance of a complete radiation safety strategy that includes secure storage, worker and public education, rapid emergency response capabilities. By addressing these issues, governments and regulatory agencies can help to prevent such incidents, protect the public's safety, and guarantee the benefits of radioactive materials to meet up against the necessary precautions.

1.4 Recommendations

The Samut Prakan radiation accident exposed severe flaws in the processing, storage, and disposal of radioactive materials. To avoid such events, these recommendations suggest increasing public awareness, enhancing emergency response, and developing a centralized system for tracking and disposing of discarded radioactive materials. Implementing these practices can help protect public health and increase safety in industries and communities that handle radioactive materials.

The Samut Prakan incident made clear how urgently the public needs to be made more aware of radiation risks and how to identify radioactive materials. Improving warning systems with multilingual safety labels on all radioactive devices and straightforward, widely understood symbols is one important suggestion. Public awareness campaigns and basic warning indicators can help stop this. All equipment containing radioactive elements should have standard symbols and basic safety information in several languages. Community awareness campaigns in areas near storage facilities can teach people about radiation risks and what to do if they find a suspicious item [9]. The response to the Samut Prakan accident showed a need for better emergency training. Regular practice for radiation emergencies would help responders act quickly and safely. Training could focus on shielding, safe handling, and quick recovery of radioactive sources. This training should be available for emergency teams and anyone who works with radioactive materials.

Last but not least, a centralized system for tracking and disposing of radioactive sources would significantly reduce the likelihood of lost or improperly stored items. A system like this would keep track of every source from use to disposal, guaranteeing that residual radioactive elements are either appropriately disposed of

after they become inactive or stored safely. Additionally, centralized tracking would lower the cost and increase accessibility of disposal, encouraging license holders to move their sources securely rather than taking the chance of hazardous storage. This strategy would reduce potential risks for both the public and employees by filling a significant gap in the management of radioactive sources [10].

2. Chernobyl Disaster

2.1 Introduction

A 38 years ago, on 26 April 1986, a catastrophic event occurred in Ukraine that would forever change the world. The Chernobyl Power Station, located on the outskirts of Pripyat, Ukraine, became the site of one of the worst and largest man-made disasters in history of mankind. Reactor Number 4 of the Chernobyl Power Plant suffered a violent explosion, releasing massive amounts of radioactive material into the atmosphere. The fallout from this explosion not only affected the immediate area surrounding the power plant in Ukraine but also spread across vast regions of Russia, Belarus, and Europe, and even reached other continents. This disaster marked a turning point in the history of nuclear power, with far-reaching consequences for the environment, human health, and global energy policies.

The explosion was caused by a combination of human error, flawed reactor design, and insufficient safety protocols. In the days leading up to the disaster, a late-night safety test was being conducted at Reactor 4 to assess its ability to maintain cooling during a power outage. The test, however, was conducted under unsafe conditions, with the reactor operating at low power and important safety systems disabled. A series of mistakes and misjudgments by the plant operators, combined with the reactor's unstable design, led to an uncontrollable power surge. This surge resulted in the explosion, which released an unprecedented amount of radiation.

The radioactive materials released into the atmosphere included iodine-131, cesium-137, and strontium-90. Iodine-131, with a half-life of eight days, posed an immediate threat to human health, particularly to the thyroid gland. Cesium-137 and strontium-90, both with much longer half-lives of around 30 years, contributed to long-term environmental contamination. These radioactive isotopes were carried by winds over large areas, affecting vast regions of Europe and beyond, leaving a lasting legacy of contamination that continues to affect the environment and public health today [11].

2.2 Chronology of Accident

In 1986, when the accident occurred, Chernobyl was one of four nuclear power stations in Ukraine and was part of a broader effort to rapidly expand the country's nuclear energy capacity. What is RBMK? It is Reaktor Bolshoy Moshchnosti Kanalny, or "High Power Channel-type Reactor". The Chernobyl plant had four RBMK-1000 reactors, with the first unit, Unit 1, starting electricity generation in 1977. Unit 4, where the accident took place, began generating electricity in 1983. There were two more new unit which is unit 5 and unit 6 under construction in 1986, but stopped after the disaster happened.

The RBMK-1000 is a Soviet-designed graphite-moderated, pressure tube reactor that uses slightly enriched uranium dioxide fuel (2% U-235). It is a boiling water reactor, with two loops sending steam directly to the turbines, bypassing a heat exchanger. Water is pumped into the bottom of the fuel channels, where it boils as it moves up the pressure tubes, creating steam that drives two 500 MWe turbines. The water serves as both a coolant and a source of steam for the turbines. The pressure tubes are vertical and contain zirconium alloy-clad uranium dioxide fuel, with coolant flowing around it. The fuel channels extend through the lower and upper plates of the core, welded at both ends. A specialized refueling machine allows fuel bundles to be replaced without shutting down the reactor.

Reactor Unit 4 at Chernobyl was scheduled to shut down for planned maintenance on April 25, 1986. Chief Engineer N. M. Fomin developed a plan that involved conducting tests that bypassed the reactor's safety systems while it was offline. During this time, electricity would be supplied by the kinetic energy of the turbine's rotor blades, with the plant's equipment completely de-energized. Similar tests had been proposed to other nuclear plants, but they had all refused due to the risks involved. Despite this, the management at

Chernobyl decided to proceed with the test. However, what was the point of this test? This test was aimed at simulating a power outage and assessing the ability of the reactor to provide backup power during such an event. The test also involved running the reactor at a very low power level, as low as 1% of its full power capacity. This allowed operators to assess how the reactor would behave under low power and how long it could provide power to the plant in case of a grid failure [12].

What really happened that day? At 1 p.m. on April 25, 1986, the operational staff began lowering the power of Reactor No. 4, which had been running at 3,000 megawatts (thermal) within normal parameters. The power reduction was ordered by Dyatlov, the deputy chief engineer overseeing the operations of Reactors No. 3 and No. 4, who had prepared Reactor No. 4 for the testing program approved by Fomin. At 1:05 p.m., Turbogenerator No. 7 was disconnected from the grid while the reactor's thermal output was at 1,600 megawatts (thermal). Power for the unit's essential systems, including four main circulation pumps, two electric feed pumps, and other equipment, was redirected to the bus-bars of Turbogenerator No. 8, which remained online and was designated for the tests outlined by Fomin.

At 2 p.m., as part of the experimental program, the emergency core cooling system (ECCS) was deliberately disconnected from the multiple forced circulation loop. This was one of Fomin's most critical and fatal errors. The disconnection was intentional to prevent the cold water from the ECCS tanks from entering the hot reactor, which could have caused a thermal shock. Later, when the prompt neutron power surge occurred and the main circulation pumps were turned off, leaving the reactor without cooling water, the 350 m³ of emergency water in the ECCS tanks could have been the key to controlling the situation. This water could have suppressed the reactor's reactivity void coefficient, a critical factor that determines how steam affects the nuclear reaction. In the RBMK, like in other graphite-moderated reactors, the formation of steam tends to increase the chain reaction, exacerbating the instability. Anyone would think that putting safety systems at risk in a nuclear reactor, particularly one already in a fragile state, is a huge error. The fact that he made this decision on purpose, knowing it could lead to serious consequences, would likely be seen as a serious lapse in judgment [13].

However, the operators received a request from Kiev to continue supplying electricity until 11:10 p.m., so the test was delayed. At 11:10 p.m., the reactor power had been reduced to 720MW. About 30 minutes later, the power output unexpectedly dropped to just 30MW. This sudden drop is believed to have been caused by an issue with the operation of the automatic control rods. By 1:00 a.m., the operators had managed to stabilize the reactor power at 200MW by removing some of the control rods. Over the next 20 minutes, they adjusted the coolant flow rate, which led to significant changes in the temperature of the inlet water. During this time, the reactor was described as being unstable. The coolant flow was almost entirely liquid water with no steam mixed in. At 1:22 a.m., the operators received an automatic warning indicating that the reactor should be shut down immediately, but they ignored this warning. At 1:23 a.m., the test proceeded, even though the reactor power was already too low, the number of control rods in the reactor was only half of what was needed for safe operation, and some safety systems had been deliberately disabled to carry out the test. The test postponement by the Kiev load dispatcher, shifting it from 2 p.m. on April 25 to 1:23 a.m. on April 26, ended up directly leading to the explosion. Here is the most interesting story about the Chernobyl Disaster in my opinion: the 'Chernobyl Suicide Mission'. Which involves three heroes: Alexei Ananenko, Valeriy Bezpalov and Boris Baranov risked their lives to enter a flooded, radioactive area beneath Reactor 4 to manually open valves and drain a large pool of water, preventing a potentially catastrophic steam explosion [14].

After the initial explosion, the reactor core was in a sub-critical condition. The temperature could increase to the point where it melts through the floor of the reactor and the concrete below. The coolant water reservoirs are directly underneath the reactor. If the core burns through and gets to the water, there will be steam explosion and that will cause further ejection of radioactive material. This means Pripyat, Kyiv, Moscow and even Europe will be contaminated. To prevent this scenario, plant engineers devised a plan to drain the water from the basement. However, the valves that controlled the drainage system were located in a flooded basement area heavily contaminated with radiation. Volunteers were needed to enter the dark, radioactive water, locate the valves, and open them manually.

Alexei Ananenko, Valeri Bezpalov, and Boris Baranov stepped forward for the mission. Wearing only basic protective gear, they entered the radioactive water with flashlights, using their knowledge of the plant layout

to navigate through the dark corridors. They successfully located and opened the necessary valves, allowing the water to drain and averting the threat of a secondary explosion. The radiation fallout is already horrifying, like something from a nightmare. It's chilling to imagine what might have happened if no one had courageously stepped up to drain the radioactive water, a second explosion could have made the devastation even worse.

The evacuation during the Chernobyl disaster was delayed, which made the situation worse. The explosion happened on April 26, 1986, but it took more than 24 hours for authorities to start evacuating people. They didn't understand how serious the situation was at first, and this delay meant that many residents were exposed to dangerous radiation for a longer time than needed [15].

In addition to the delayed response, there was a major issue with the lack of clear and accurate information provided to the public. When the evacuation of Pripyat was finally ordered on April 27, people were told that the move would be temporary, which led them to believe they would soon return to their homes. As a result, many residents left with little more than the clothes on their backs and did not take necessary belongings or make long-term arrangements. This misinformation contributed to confusion and panic, leaving the evacuees unprepared for the long-term displacement they would face.

The evacuation process itself was rushed and poorly planned, adding to the chaos and confusion. People were quickly loaded onto buses without sufficient preparation or information. They were taken to temporary shelters, often with no clear idea of where they were going or how long they would be away from their homes. Some residents had to wait outside for hours, exposed to radiation, before being transported. The lack of organization and preparation in the evacuation process only increased the stress for those affected and contributed to higher radiation exposure than was necessary.

The total number of deaths caused by the Chernobyl disaster is still debated. The immediate deaths from the explosion and radiation exposure number around 30 people, but the long-term impact is far greater. Some estimates suggest that up to 90,000 people could have died from the long-term effects of radiation exposure, including cancer and other radiation-related diseases. Other sources suggest that the total death toll could be as high as 100,000 or more, but these numbers are not confirmed and vary depending on the method of estimation [16].

The health effects of Chernobyl are still being studied, and the full extent of the disaster's impact on both human health and the environment will continue to be analyzed for many years. The disaster highlighted the serious risks of nuclear power and its long-term consequences on public health.

2.3 Lessons Learnt

This Story offers us numerous of lessons such as prioritize safety protocols over efficiency. The disaster underscores the importance of safety protocols over operational or economic efficiency. The rush to conduct the safety test without proper preparation and the disabling of safety systems led to severe consequences. Nuclear operations, or any high-risk industries, must prioritize safety above all else. Fomin's actions would probably seem reckless and irresponsible. The RBMK reactor had a positive void coefficient, which means that as water in the reactor core turned into steam (creating "voids" or bubbles), it actually increased the reactor's reactivity instead of reducing it. In most reactors, steam formation lowers reactivity, helping to keep the reactor stable. However, in the RBMK design, more steam led to more reactivity, creating a dangerous feedback loop that could trigger uncontrollable reactions, especially at low power levels, precisely what happened during the test. Disconnecting the emergency cooling system from the reactor, especially during such a dangerous experiment, looks like a major mistake. Looking back, it seems like Fomin ignored basic safety rules and underestimated the dangers of messing with the reactor's cooling system during such a high-risk test. To someone without technical expertise, it would feel like he prioritized the experiment over the safety of both the plant and the people around it [17].

Next, the Chernobyl disaster taught us that, especially in high-risk settings like nuclear power, systems must be designed to handle human mistakes. The reactor had a dangerous design flaw: as cooling water turned to steam, it became even more reactive, meaning any error could quickly escalate. The design assumed operators would always manage this risk, but in high-pressure situations, people can make mistakes. Safer designs build in automatic shutdowns, clear controls, and straightforward safety systems that kick in without

needing complex human actions. Regular training, realistic practice drills, and a culture that puts safety first are also critical, ensuring that even if something goes wrong, the worst outcomes can be prevented.

Moreover, The Chernobyl disaster highlighted the catastrophic consequences of human error in high-risk environments. While the reactor had design problems, the explosion happened because workers made errors, like ignoring safety rules and making bad decisions during the test. This teaches us that it's important to have proper training, clear instructions, and safety systems in place to prevent mistakes. In jobs with high risks, everyone needs to fully understand the dangers and follow safety procedures to avoid accidents.

One important lesson from the Chernobyl disaster is the need for clear and open communication during a crisis. At first, the Soviet authorities were very slow to admit how bad the disaster was and didn't share important information with the public or other countries. This lack of transparency made things worse, causing more people to be exposed to radiation and leading to more lives being lost. It shows how important it is for the government and officials to communicate honestly and quickly during emergencies to avoid panic and confusion. Without good communication, people can't make informed decisions, which can lead to even greater harm [18].

The Chernobyl disaster teaches us the importance of individual courage and responsibility in moments of crisis and reminds us of our ability to make a difference through selfless actions. While most of us may not face situations as extreme as those faced by the Chernobyl workers, we can still apply these principles in our own lives. In high-stakes situations, whether at work, in our communities, or with our families, we should remember the impact of stepping up to help, even when it involves personal risk or sacrifice. This lesson encourages us to be aware of potential dangers, take responsibility, and act courageously when others' safety and well-being depend on it. Each of us can make a difference by prioritizing safety, communicating honestly, and being prepared to act when faced with difficult decisions.

2.4 Recommendations

First of all, instead of giving recommendation about what could be done to prevent Chernobyl disaster. I would like to recommend a few things you can explore in the meantime to learn more about this historic event. Several movies, like Chernobyl 1986 and Chernobyl Diaries, provide thrilling and intense portrayals of the tragedy and its eerie aftermath. Chernobyl 1986 offers a dramatic and emotional dive into the personal sacrifices made in the wake of the explosion, while Chernobyl Diaries brings horror elements into the story, setting its scenes within the haunting, abandoned ruins of Pripjat. Additionally, HBO's mini-series Chernobyl provides a more grounded, harrowing portrayal based on the actual events of 1986. This series meticulously follows real individuals who fought to contain the disaster, with characters named after the true heroes who faced life-changing risks in the aftermath. Each film or series offers a unique, gripping perspective on Chernobyl, making it possible to learn about the disaster's impact while also experiencing the tension and emotional depth of those who lived through it.

One of the key recommendations from the Chernobyl disaster is to prioritize nuclear reactor designs that incorporate advanced safety features capable of preventing accidents, even in extreme situations. Reactors should include fail-safe mechanisms, such as negative reactivity feedback, which automatically reduces power output if conditions become unsafe. Additionally, robust containment structures are essential to prevent radiation from escaping in the event of a malfunction. These reactors should also be designed to minimize human error by having automated systems that can override unsafe actions if necessary. By focusing on engineering that prioritizes stability and resilience, the nuclear industry can better protect both operators and the surrounding environment from potential hazards [19].

Another recommendation from Chernobyl is the importance of a strong safety culture in nuclear facilities and other high-risk industries. This means that everyone, from plant operators to management, must prioritize safety above all else and follow clear safety procedures. Workers should have regular training to keep their skills sharp and practice safety drills to be prepared for emergencies. It's also crucial that employees feel comfortable speaking up about any safety concerns without fearing punishment. Building this kind of safety-focused environment helps prevent accidents and ensures that everyone takes safety seriously every day.

Another recommendation from Chernobyl is the need for long-term monitoring of areas affected by nuclear disasters to manage ongoing health and environmental impacts. This means regularly checking radiation levels, providing continuous medical care for affected people, and supporting communities in these areas. Monitoring programs also help scientists learn more about the long-term effects of radiation exposure, allowing them to develop better treatments and safety measures. By keeping a close watch on both health and environmental conditions, we can better protect people over time and improve nuclear safety practices for the future.

Another recommendation from Chernobyl is the need for strong regulatory oversight and independent audits of nuclear facilities. This means that external organizations should regularly inspect nuclear plants to ensure they are following safety standards and not cutting corners. Independent audits help identify any safety issues or potential risks that the plant's management may overlook or downplay. By having unbiased checks in place, we can ensure that safety protocols are being followed properly and that any weaknesses are addressed before they lead to accidents. This type of oversight is crucial for maintaining high safety standards in the nuclear industry. In the case of a nuclear accident, it is very important to communicate clearly and honestly with the public and other countries. Sharing accurate information helps prevent panic and confusion. It also allows people to evacuate quickly if needed and helps build trust between the public and authorities. When countries share information with each other, they can work together more quickly to reduce the damage and respond to the crisis in a better way. Transparency and good communication are key to managing any disaster.

3. The Church Rock Uranium Mill Spill

3.1 Introduction

The Church Rock Uranium Mill Spill, which occurred on July 16, 1979, is recognized as the largest accidental release of radioactive material in U.S. history. It unfolded in Church Rock, New Mexico, a small community within the Navajo Nation, underscoring the environmental and social impacts of uranium mining on Indigenous lands. The disaster began when an earthen tailings dam at the United Nuclear Corporation's uranium mill failed, releasing over 93 million gallons of radioactive wastewater and 1,100 tons of solid radioactive mill waste into the Puerco River. The spill spread toxic substances such as uranium, thorium, radium, and heavy metals downstream, contaminating water sources and soil over an extensive area.

The immediate aftermath of the spill brought devastating consequences to the surrounding ecosystem and communities. Radioactive materials flowed through the Puerco River, a critical water source for Navajo livestock and farming. This contamination rendered the water unsafe for agricultural, domestic, and spiritual use, a significant blow to the Navajo people who relied on it for their livelihoods. For decades, the health impacts have continued to surface. Elevated rates of cancer, kidney disease, and other illnesses linked to long-term exposure to radiation have plagued the local population. Many Navajo residents remain exposed to uranium waste that was never fully cleaned up, further exacerbating the crisis of environmental justice.

The Church Rock spill exemplifies systemic negligence and environmental racism. Despite its massive scale, the disaster received far less attention than comparable nuclear accidents, such as the Three Mile Island incident, which occurred the same year. Advocacy groups argue this disparity in attention underscores the marginalization of Indigenous communities in addressing environmental crises. Efforts to remediate the site have been slow and insufficient, leaving significant contamination in place. Advocacy for justice has continued, with calls for more comprehensive cleanup efforts, health support for affected communities, and accountability from the mining industry and federal government [20].

The Church Rock spill was part of a larger pattern of environmental degradation and exploitation associated with uranium mining during the Cold War. Thousands of abandoned uranium mines dot the Navajo Nation, many of which continue to leak radioactive material into the environment. This legacy has had lasting implications for public health, environmental justice, and trust in federal and corporate entities. While cleanup efforts have been initiated, progress has been hindered by funding shortages and logistical challenges. Navajo leaders and environmental justice organizations continue to push for comprehensive remediation and compensation for affected communities. The spill has also galvanized awareness about the long-term impacts

of uranium mining on Indigenous lands, sparking wider conversations about resource extraction, environmental justice, and Indigenous sovereignty.

3.2 Chronology of the Accident

The summary for the chronology of the accident based on Table 1 below.

Table 1

Summary of the accident

	Chronology's Story
Background: Church Rock Uranium Operations	<p>Location: Church Rock, a community in the Navajo Nation in New Mexico, was central to uranium mining activities during the mid-20th century. The region became a focal point for uranium extraction during the Cold War.</p> <p>Facility: The spill originated at the United Nuclear Corporation (UNC) mill. The company processed uranium ore to produce yellowcake, a concentrated form of uranium used in nuclear fuel production.</p> <p>Tailings Pond: The UNC mill used a dam to contain radioactive tailings— byproducts of uranium processing. This earthen dam held 93 million gallons of radioactive wastewater and 1,100 tons of solid mill waste.</p>
The Incident: July 16, 1979	<p>Dam Failure: Early in the morning, the dam on the tailings pond failed, allowing the radioactive waste to spill into the Puerco River.</p> <p>Extent of Spill:</p> <ul style="list-style-type: none"> -Approximately 94 million gallons of radioactive effluent and 1,100 tons of contaminated sediment were released. -The spill carried hazardous substances, including uranium, thorium, radium, and other heavy metals. <p>Contamination Path: The Puerco River, a key water source for local communities, was severely contaminated. The river flowed through Navajo Nation lands, spreading radioactive material downstream.</p>
Immediate Response	<p>Delayed Notification: Local residents and Navajo Nation authorities were not immediately informed. Many people unknowingly continued to use the river water for livestock and personal needs.</p> <p>Federal and Corporate Actions:</p> <ul style="list-style-type: none"> -The Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) responded to the spill but struggled to address the scale of contamination. -UNC initiated some cleanup efforts but focused mainly on visible damage rather than long-term contamination.
Health and Environmental Impacts	<p>Health Effects:</p> <ul style="list-style-type: none"> -Residents exposed to radioactive water and dust reported health issues, including cancers and kidney problems, over time. -Livestock, which relied on the Puerco River, were also exposed, threatening food supplies and livelihoods. <p>Environmental Damage:</p> <ul style="list-style-type: none"> -Soil and water in the affected areas remained contaminated for decades. -Radioactive materials persisted in sediments, creating long-term ecological and public health risks.
Long-Term Impacts and Advocacy	<p>Ongoing Contamination:</p> <ul style="list-style-type: none"> -Studies found that radioactive materials remained in the area for decades after the spill. -Groundwater contamination became a major concern, affecting drinking water for Navajo communities. <p>Advocacy and Awareness:</p> <ul style="list-style-type: none"> -Navajo activists and organizations like the Navajo Nation Environmental Protection Agency (NNEPA) brought attention to the spill and its consequences.

Policy Changes and Cleanup Efforts	<p>-Calls for justice and reparations were part of a broader movement to address environmental racism and the disproportionate impact of uranium mining on Indigenous communities.</p> <p>Federal Programs: In the 1990s and 2000s, the U.S. government began funding some cleanup projects under the Navajo Uranium Cleanup Program.</p> <p>Superfund Site Designation: The Church Rock site was designated as part of the Superfund program, aimed at cleaning up hazardous sites. However, progress has been slow.</p> <p>Continued Advocacy: The Navajo Nation continues to demand comprehensive cleanup and compensation for affected residents.</p>
Legacy	<p>The Church Rock spill remains a stark reminder of the environmental and social costs of nuclear energy and resource extraction. It highlights systemic neglect of Indigenous communities, who often bear the brunt of environmental disasters.</p>

3.3 Three Lessons Learnt from the Church Rock Uranium Mill Spill Accident

The Church Rock uranium mill spill in New Mexico on July 16, 1979, remains one of the largest radioactive accidents in U.S. history. It released approximately 94 million gallons of radioactive waste into the Puerco River, affecting the Navajo Nation and its surrounding communities. This catastrophic event provides several critical lessons about environmental safety, corporate responsibility, and public health.

3.3.1 The Importance of robust regulatory oversight

The Church Rock disaster underscored the critical role of stringent regulations and oversight in industries involving hazardous materials. The spill occurred due to the collapse of a tailings dam designed to contain radioactive waste. Subsequent investigations revealed inadequate engineering and oversight during the dam's construction and maintenance. The event highlights the need for rigorous design standards, periodic safety assessments, and proactive monitoring systems for industrial facilities handling toxic substances. It also points to regulatory gaps at the time, with agencies like the Nuclear Regulatory Commission (NRC) being criticized for insufficient enforcement and oversight. A key takeaway is that regulatory agencies must prioritize safety over cost-saving measures and enforce compliance to prevent such accidents. Furthermore, the disaster emphasizes the necessity for industries to adopt the highest safety protocols, even in remote or marginalized areas [21].

3.3.2 Environmental justice and the protection of vulnerable communities

The Church Rock spill disproportionately affected the Navajo Nation, exposing systemic environmental injustices faced by Indigenous communities. Despite the scale of the disaster, the response from federal and state authorities was notably slow and inadequate compared to other environmental crises. Many Navajo residents relied on the Puerco River for drinking water, livestock, and farming, making the spill's impact devastating. This incident highlights the ongoing need to prioritize the protection of marginalized communities from industrial pollution. It also stresses the importance of involving local populations in decision-making processes about projects that could impact their environment and health. Addressing environmental justice requires equitable cleanup efforts, transparency, and policies that ensure corporations and governments are held accountable for environmental harms inflicted on vulnerable groups.

3.3.3 Long-term health and environmental monitoring

The Church Rock spill demonstrates the far-reaching consequences of radioactive contamination on human health and ecosystems. The spill released uranium, thorium, and other toxic materials into the environment, which remained in the soil, water, and air for decades. Many residents were exposed to these harmful substances, leading to increased risks of cancer, kidney disease, and other health issues.

One of the critical lessons is the need for comprehensive and long-term health monitoring for affected populations. Governments and corporations must invest in ongoing medical care, scientific research, and environmental rehabilitation to mitigate the lasting effects of such disasters. Additionally, the Church Rock spill underscores the importance of community education on potential risks and proper protective measures to ensure residents are better prepared to respond to future industrial accidents.

In summary, the Church Rock uranium mill spill serves as a reminder of the consequences of weak regulations, the ethical obligation to protect vulnerable communities, and the importance of addressing the long-term impacts of environmental disasters. By learning from this tragedy, policymakers, industries, and communities can work toward creating a safer and more equitable future.

3.4 Recommendations

The Church Rock uranium mill spill, which occurred on July 16, 1979, in New Mexico, stands as one of the most significant environmental disasters in U.S. history. Despite its profound implications, this event often receives less attention than other environmental crises. This journal explores the lessons learned from the incident and provides recommendations to address similar risks in uranium mining and milling operations. Additionally, it offers insights for policymakers, industry stakeholders, and affected communities, highlighting the importance of environmental justice and sustainable practices. The Church Rock uranium mill spill was a catastrophic release of 1,100 tons of solid radioactive mill waste and 93 million gallons of acidic, radioactive liquid into the Puerco River. It remains the largest accidental release of radioactive material in the United States. This disaster primarily affected the Navajo Nation, exacerbating the historical inequities faced by Indigenous communities. The spill highlighted the gaps in regulatory oversight, the underestimation of long-term environmental consequences, and the disproportionate impact on vulnerable communities. The incident continues to inform modern environmental policies and serves as a stark reminder of the dangers posed by poorly regulated mining operations.

3.4.1 Strengthening regulatory frameworks

One of the primary lessons from the Church Rock spill is the need for robust regulatory oversight. At the time, uranium milling operations were regulated under fragmented policies that failed to address cumulative risks effectively. Enforce stricter regulations under a unified framework, such as improving the Nuclear Regulatory Commission's (NRC) oversight and ensuring compliance with the Clean Water Act and other environmental laws.

3.4.2 Community involvement in decision-making

The Navajo Nation had little input into the operations or risk management plans of the uranium mill. This lack of representation exacerbated the community's vulnerability. Mandate meaningful consultation with affected communities, ensuring they have access to information and a voice in environmental decisions that impact them.

3.4.3 Environmental monitoring and transparency

The spill revealed the inadequacy of monitoring systems to detect and mitigate environmental harm promptly. Establish comprehensive monitoring programs for all uranium mining and milling sites. Data should be transparently shared with stakeholders, including local communities.

3.4.4 Long-term remediation strategies

The Church Rock spill caused extensive contamination of the Puerco River, which persisted for decades. Remediation efforts have been slow and insufficient. Implement long-term cleanup plans that include the

latest technologies for radioactive waste containment and restoration of ecosystems. Secure federal and state funding to ensure timely remediation.

3.4.5 Health impact assessments and support

The spill resulted in significant health risks for the Navajo Nation, including cancer and other radiation-related illnesses. Conduct comprehensive health impact assessments and provide medical support for affected populations. This should include funding for local healthcare infrastructure and education about radiation risks.

3.4.6 Transition to sustainable practices

The incident underscores the need to move away from hazardous energy production methods toward more sustainable alternatives. Promote investment in renewable energy sources and reduce dependency on uranium-based power production. Establish transition programs for communities economically dependent on mining [22].

The Church Rock uranium mill spill offers critical lessons in environmental management, regulatory oversight, and social justice. By addressing the systemic flaws revealed by this disaster, governments and industries can work toward preventing similar events in the future. Upholding environmental justice principles is essential to ensure that marginalized communities no longer bear the brunt of environmental degradation.

4. Conclusion

4.1 Samut Prakan Radiation Accident

In conclusion, the disaster shows serious safety gaps in the handling, storage, and disposal of radioactive sources, which are commonly used in industrial and medical applications. The primary cause of this incident was faulty storage, as the cobalt-60 source was left unsecured, allowing untrained persons to mistakenly dismantle it, resulting in serious radiation exposure and fatalities. This disaster highlights the critical necessity for strict safety protocols and regulatory monitoring at all stages of radioactive source management, from active use to disposal. Furthermore, the accident highlights the significance of a centralized tracking mechanism for radioactive sources. Without a reliable mechanism to monitor the state and location of these sources, the risk of unsecured sources rises, as demonstrated in this case. A centralized disposal system would give license holders with accessible and cost-effective options for properly decommissioning radioactive sources, avoiding instances in which storage is neglected or becomes dangerous. Finally, the Samut Prakan tragedy serves as an urgent reminder of the dangers of regulatory and procedural inadequacies in radiation safety. Stricter storage restrictions, public education, and centralized tracking could not only improve community safety near such sites, but also raise the bar for accountability in radioactive material management.

4.2 The Chernobyl disaster

The Chernobyl disaster is one of the worst events in history and has taught us many important lessons. The explosion of Reactor 4 happened because of design problems, human mistakes, and poor management decisions. This caused many deaths, serious radiation exposure, and long-term effects on people and the environment. The evacuation was delayed, and people weren't properly informed, which made the situation worse. The safety culture at the plant was weak, and safety wasn't treated as a priority.

4.3 The Church Rock Uranium Mill

The Church Rock uranium mill spill on July 16, 1979, is considered the largest accidental release of radioactive material in U.S. history. This disaster occurred when a dam holding liquid and solid uranium mill

waste near Church Rock, New Mexico, failed. The breach released approximately 94 million gallons of radioactive wastewater and 1,100 tons of solid tailings into the Puerco River, impacting the predominantly Navajo community in the area. The spill highlighted systemic issues of environmental oversight and corporate negligence. The dam, built on unstable geologic formations and with inadequate safeguards, had shown signs of vulnerability for years. Despite the severity of the event, public awareness and governmental response were minimal compared to other nuclear incidents like the Three Mile Island disaster earlier that year. The environmental and health impacts were profound. Radioactive contaminants seeped into the soil, water, and air, affecting local residents who relied on the Puerco River for livestock and personal use. Many reported immediate health issues like burns and sores and have faced long-term consequences, including increased cancer risks and chronic health conditions. The cleanup efforts were insufficient, leaving lasting contamination that continues to affect the Navajo Nation today.

Acknowledgement

This research was not funded by any grant.

References

- [1] Karim, Ridoan, and Eric Yong Joong Lee. "The global quest for nuclear safety, security, safeguard, and liability: an analysis of international legal and regulatory framework for nuclear energy." In *Navigating Nuclear Energy Lawmaking for Newcomers: An Asian Perspective*, pp. 59-99. Singapore: Springer Nature Singapore, 2023. https://doi.org/10.1007/978-981-99-5708-8_3.
- [2] Ya-anant, Nanthavan, Kanokrat Tiyaun, and Kittiphong Saiyut. "Radiological accident and incident in Thailand: lesson to be learned." *Radiation protection dosimetry* 146, no. 1-3 (2011): 111-114.
- [3] Pongsoi, Parinya, and Somchai Wongwises. "A review on nuclear power plant scenario in Thailand." *Renewable and Sustainable Energy Reviews* 24 (2013): 586-592. <https://doi.org/10.1016/j.rser.2013.03.038>.
- [4] Office of Atoms for Peace (OAP). *Annual Report on Radiation Safety and Regulatory Activities in Thailand*. No. OAP-2019-01. Bangkok: Office of Atoms for Peace (2019). <http://www.oap.go.th>.
- [5] Sukna, K. "Radioactive Contamination Discovered in Samut Prakan Facility." *Bangkok Post*, September 8 (2015). <https://www.bangkokpost.com>.
- [6] International Atomic Energy Agency (IAEA). *Radiation Safety in Southeast Asia*. (2020). <https://www.iaea.org/topics/radiation-safety>.
- [7] World Nuclear Association. 2021. *Nuclear Power in Thailand*. <https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-thailand.aspx>.
- [8] Yap, Chee Kong, and Khalid Awadh Al-Mutairi. "Chernobyl nuclear catastrophe: lessons for sustainability and UNSDGs in health, energy, and environmental recovery." *Frontiers in Public Health* 13 (2025): 1552122.
- [9] Berris, Theocharis, and Madan M. Rehani. "Promoting public awareness and communicating radiation safety." *Radiological safety and quality: Paradigms in leadership and innovation* (2014): 225-239. https://doi.org/10.1007/978-94-007-7256-4_12.
- [10] Launer, Michael. "Chernobyl: The History of a Nuclear Disaster." (2019): 119-125. <http://www.istor.org/stable/45408614>.
- [11] Ilyin, L. A., and O. A. Pavlovskij. "Radiological consequences of the Chernobyl accident in the Soviet Union and measures taken to mitigate their impact (Russian Edition)." *IAEA Bulletin* 29, no. 4 (1987): 20-27.
- [12] Zablotska, Lydia B. "30 years after the Chernobyl nuclear accident: time for reflection and re-evaluation of current disaster preparedness plans." *Journal of Urban Health* 93 (2016): 407-413.
- [13] Gorbachev, Mikhail. "Chernobyl 25 years later: Many lessons learned." *Bulletin of the Atomic Scientists* 67, no. 2 (2011): 77-80. <https://doi.org/10.1177/0096340211399746>.
- [14] Plokhly, Serhii. *Chernobyl: The Forgotten Tragedy*. London: Penguin Books (2019).
- [15] International Nuclear Safety Advisory Group. *Summary report on the post-accident review meeting on the Chernobyl accident*. No. 1. International Atomic Energy Agency, 1986.
- [16] Schmid, Sonja D. "When safe enough is not good enough: Organizing safety at Chernobyl." *Bulletin of the Atomic Scientists* 67, no. 2 (2011): 19-29. <https://doi.org/10.1177/0096340211399404>.
- [17] Bennett, Burton, Michael Repacholi, and Zhanat Carr. "Health effects of the Chernobyl accident and special health care programmes." In *Report of the UN Chernobyl Forum Expert Group "Health"*. Geneva: World Health Organization. 2006.
- [18] ElBaradei, M. "The enduring lessons of Chernobyl." (2005).

- [19] Oriol Planas, "Causes of the Chernobyl Accident: The Worst Disaster in History," Nuclear Energy, 2023, <https://nuclear-energy.net/>
- [20] Geist, Edward. "Political Fallout: The Failure of Emergency Management at Chernobyl." *Slavic Review* 74, no. 1 (2015): 104-126. <https://doi.org/10.5612/slavicreview.74.1.104>
- [21] Dion-Schwarz, Cynthia, Sarah E. Evans, Edward Geist, Scott Warren Harold, V. Ray Koym, Scott Savitz, and Lloyd Thrall. *Technological Lessons from the Fukushima Dai-Ichi Accident*. RAND, 2016.
- [22] Qadir, Sikandar Abdul, Hessah Al-Motairi, Furqan Tahir, and Luluwah Al-Fagih. "Incentives and strategies for financing the renewable energy transition: A review." *Energy Reports* 7 (2021): 3590-3606. <https://doi.org/10.1016/j.egy.2021.06.041>.