NUCLEAR DISASTER: THE CHERNOBYL CASE STUDY

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THE BIGGEST NUCLEAR DISASTER IN THE WORLD

CHERNOBYL CASE STUDYCASE STUDY & POWER PLANT OF BD

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I. Introduction

The Chernobyl nuclear accident, which happened on April 26, 1986, at the Chernobyl Nuclear Power Plant in Ukraine, some 20 kilometers south of the Belarusian border, is still considered one of the most momentous events in contemporary history. The disaster caused a sustained leak of radioactive elements into the atmosphere, impacting not just the nearby area but also extending over the northern hemisphere, particularly in Europe. While the direct radiological impact outside of Europe was relatively modest, the inhabitants of Belarus, Ukraine, and Russia continued to face long-term socioeconomic and health impacts.

Fig1: Chernobyl's evacuation site
Source: CIA
https://www.cia.gov/readingroom/docs/CIA-RDP93T01142R000100360001-3.pdf

This catastrophe also generated global concern about the safety of the use of nuclear power spurring greater investments in reactor safety research and emergency planning over the next 16 years. Although a period of time, the wider community in Chernobyl remains, with continuous debates over its health consequences, particularly the alleged increase in thyroid cancer cases. Given these conditions, it is critical that we revisit our knowledge of the disaster's effects, examine the lessons gained, and include recent information on public health and environmental damage. This work seeks to provide a complete analysis of these elements, as well as insights to guide future nuclear safety and public health policies and measures.

II. Background of the incident

The Chernobyl nuclear power plant disaster was caused by a series of systemic failings, including defective design and inadequate worker training. Unprecedented radiation levels were released into the atmosphere by the huge explosion of Reactor 4, which was a Model RBMK-1000 reactor. Plant managers tried to solve the problem by putting the control rods inside the reactor and switched off a crucial automatic shutdown switch before to the explosion. They were ignorant, nevertheless, that this move would, because of a design flaw, intensify sensitivity. Pressure caused the nuclear reactor's 1000-ton cover plates to partially split, which set off a chain of explosions that dispersed the highly radioactive core components throughout the complex.

Reactor Unit 4 was originally planned for routine maintenance, but operators had the chance to conduct a test. The purpose of this test was to determine the slowing turbine's functioning and capacity to generate enough electrical power to run the main core cooling water circulating pumps in the event of a station power outage. The test was critical in assessing if core cooling could be maintained until the emergency diesel power source came online.

Due to the uncertainty surrounding the test, there was insufficient communication between the safety and testing departments, which resulted in a serious lapse in safety protocols. Because of this, the test was conducted without the required safety measures in place. This includes not adequately alerting operational staff to the inherent risks involved in performing the electrical test as well as any possible ramifications for nuclear safety. Furthermore, a comprehensive risk assessment and backup plans to handle any unanticipated issues that could come up during the test were lacking. The tragic series of events that culminated in the Chernobyl accident was partly caused by these safety procedure flaws.

III. Routine maintenance, Reactor and Experiments

The scheduled maintenance at the Chernobyl nuclear power plant included purposely shutting off the Emergency Core Cooling System (ECCS), which is the mechanism for cooling the reactor core. However, due to technical issues, the reactor's output of electricity plummeted unexpectedly to roughly 30 MW rather than the planned 700-1000 MW. In order to maintain the reactor's output at a higher power level of 200 MW during the test, operators breached safety standards by removing control rods, despite the reactor's known positive vacancy coefficient, which might lead to greater reactivity.

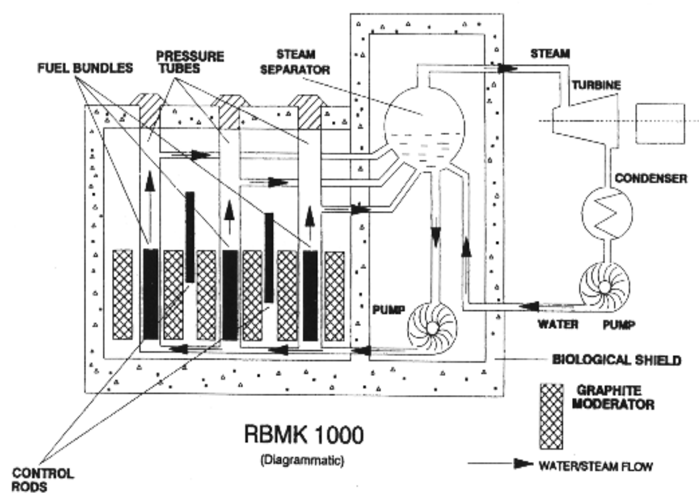

Fig2: RBMK1000 Block diagram
Source: World Nuclear Association
https://world-nuclear.org/getmedia/e76737e5-ca6c-4b74-a483-

On April 26, 1986, at 1:23 AM, engineers stopped the turbine engine during the experiment to see if its spinning could run the reactor's water pumps. Reactor power levels surged, nevertheless, when this failed to supply enough power. The somewhat warmer feed water entering the core and the slower pumping rate of the water pumps probably led to boiling at the bottom of the core, which increased power levels even further. Fuel components burst when the power level rose to 530 MW and above, aggravating the problem by generating steam and raising the positive void coefficient. Because of its graphite tip construction, control rods that were intended to regulate the reactor's core temperature jammed halfway down the reactor. Two explosions occurred, the initial one being a steam explosion, and the second being produced by hydrogen accumulation from zirconium-steam interactions. These explosions spewed fuel, moderator, and structural elements, igniting fires and releasing nearly 50 tons of radioactive substances into the atmosphere, greatly surpassing the amount released during the Hiroshima attack.

IV. Chernobyl Disaster's Immediate Impact

The Chernobyl disaster was the greatest uncontrolled release of radioactive elements into the environment from a civilian operation, creating major social and economic hardship for people in Belarus, Russia, and Ukraine. The discharge of radioactive chemicals, including iodine-131 and caesium-137, had devastating health implications for people who were exposed. It is expected that the accident expelled a significant amount of radioactive material from the reactor core, such as xenon gas, iodine, and caesium. While majority of the discharged material landed as dust and debris, lighter particles were transported by wind throughout Ukraine, Belarus, Russia, Scandinavia, and Europe.

Tragically, the disaster killed firemen who heroically responded to the early fires on the turbine building top. Despite efforts to extinguish the fires rapidly, significant radiation doses on the first day killed 28 people, including six firemen, by the end of July 1986. The firemen and power plant workers were exposed to levels high enough to produce acute radiation syndrome (ARS), which is marked by symptoms including gastrointestinal problems, headaches, burns, and fever. A whole-body dosage of 4000 to 5000 milligrams (mGy) over a short period of time would be lethal for half of those exposed, whereas doses more than 8000 to 10,000 mGy are fatal for all. The dosages received by the deceased firemen were believed to be as high as 20,000 mGy.

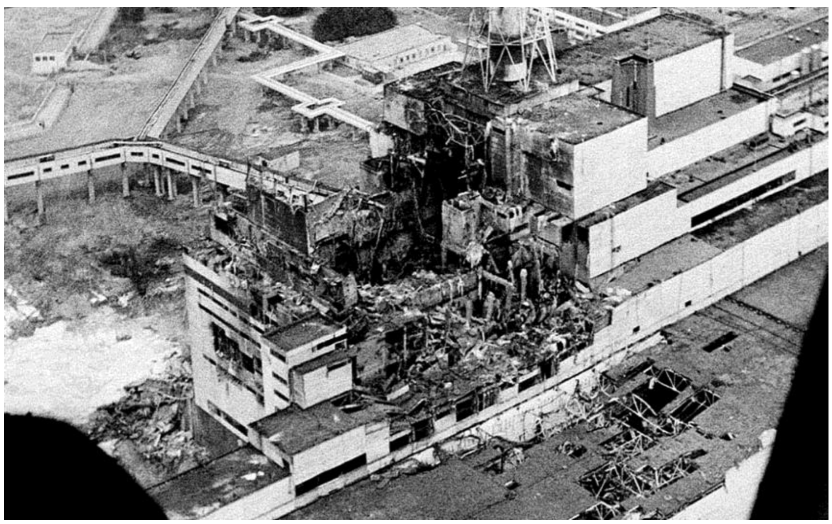

Fig3: Damaged Reactor 4 facility
Source: NBC news
https://media-cldnry.s-nbcnews.com/image/upload/t_nbcnews-fp-1200-

The Chernobyl tragedy needed enormous measures to cleanse the site and reduce additional environmental and human health threats. Over 200,000 brave volunteers, known as 'liquidators,' were deployed from across the Soviet Union to perform the grueling process of recovery and cleanup in 1986 and 1987. Despite facing heightened levels of radiation, with average exposures of about 100 millisieverts (mSv), these liquidators worked relentlessly to restore safety and stability to the damaged region. Subsequent evaluations by the United Nations Scientific Committee on the Effects of Atomic

Radiation (UNSCEAR) offered information on the average radiation exposure suffered by survivors of the disaster.

The average radiation amount in ‘strict radiation control’ zones, which housed 216,000 people, was 31 mSv over a 20-year period from 1986 to 2005, while in ‘contaminated’ regions, which housed 6.4 million people, the average dose was 9 mSv, barely over background radiation levels. The first exposure was mostly due to short-lived iodine-131, followed by worries about the long-term consequences of caesium-137. Evacuation measures were launched quickly, with the abandoning of Pripyat, the home of plant operators, and the subsequent evacuation of inhabitants. Despite obstacles, the perseverance and devotion of people working in cleaning and relocation activities have been critical in reducing the effects of the Chernobyl tragedy and encouraging rehabilitation in impacted areas.

V. Human and Health Effects

Ionizing radiation penetrates the body and interacts with tissues, causing atoms to ionize, particularly in DNA, the genetic material. The level of damage is determined by the dosage rate, smaller doses frequently allow for cell repair, but large doses can cause irreversible damage, resulting in cell death and reduced organ function. These quick and severe consequences, termed as "deterministic effects," were the leading causes of early fatalities following Chernobyl. In contrast, lesser dosages over time may not cause immediate damage because cellular repair processes compensate. However, insufficient repair may result in genetic changes, which might lead to cancer or hereditary abnormalities in the long run, known as "stochastic effects." Because low-dose health effects cannot be directly evaluated, risk estimations are based on high-dose effects, with the assumption that dosage and risk are proportionate. The International Commission on Radiological Protection (ICRP) predicts a 5% risk of deadly cancer for each sievert of whole-body exposure. Beyond physical consequences, the Chernobyl tragedy had social and psychological ramifications that influenced overall health outcomes. These include increased fear, distrust of authority, and disruptions to social structures, which exacerbate the health difficulties encountered by afflicted people. Understanding and resolving these complex health consequences is critical for complete recovery and long-term well-being.

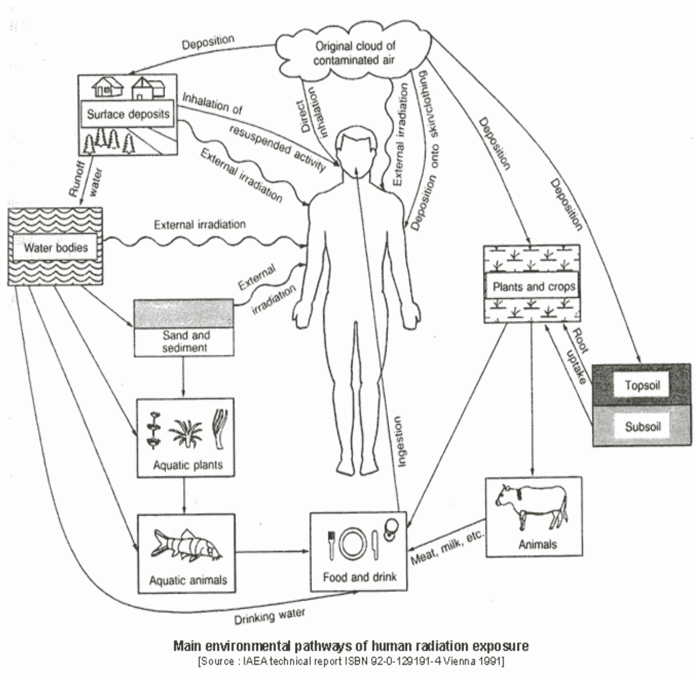

Fig4: Pathway of human radiation exposure

Source: International Advisory Committee, IAEA, 1991

https://www.pub.iaea.org/MTCD/publications/PDF/Pub885e_web.pdf

VI. Long Term impact of the accident

The Chernobyl disaster was linked to an increase in thyroid cancer cases, but its long-term influence on health is still being investigated. Initiatives like as the WHO's International Program on the Health Effects of the Chernobyl Accident (IPHECA) were established to investigate a variety of health issues, including leukemia, thyroid illness, and mental health. Long-term plans are currently being developed based on the outcomes of these investigations. Predictions indicate a slight rise in cases of cancer across Europe and the northern hemisphere, including estimations ranging from 0.004% to 0.01% over natural rates. However, places without major pollution, such as North America and Asia, are expected to incur modest health consequences. The focus has switched to the research of long-term health impacts in polluted areas, notably in the days of the Soviet Union.

Fig5: Soviet technician examines a child for radiation exposure, Kopylovo village, Kyiv, May 9, 1986
Source: Voice of America News
https://gdb.voanews.com/58282267-201C-4345-9EDE-

The International Chernobyl Project performed field research to assess the health of inhabitants living in polluted communities. While no radiation-related abnormalities were found, considerable non-radiation-related health problems were reported, which were exacerbated by unfavorable social and psychological repercussions. Concerns remain about possible future increases in thyroid cancers as a result of high thyroid dosages in youngsters. The International Chernobyl Project Report noted difficulties in determining radiation effects owing to a small sample size and data assessment constraints. Despite ambiguities, it is thought that, with the exception of thyroid disorders, detectable radiation impacts in the general population are improbable. Apart from thyroid illness, the accident's overall impact on population health is expected to be minor when compared to normal occurrence rates, according to predictions.

Statistics collected by the Russian National Medical Dosimetric Registry (RNMDR) show that illness incidence increased between 1989 and 1992, with a significant increase in malignant diseases, which might be attributable to greater surveillance and/or radiation exposure. The crude death rate amongst liquidators in the Russian Federation also rose, primarily due to respiratory infections and all malignant neoplasms, suggesting significant health hazards related with Chernobyl exposure. Prediction models built on dosimetric data predict a considerable increase in cancer mortality, peaking about 25 years after exposure, underlining the long-term health consequences for exposed populations.

However, issues in data interpretation, such as confounding factors such smoking and geographical differences in death rates, demand more observation to determine the real impact. Reports on chromosomal abnormalities among people exposed to Chernobyl radiation have shown varied results, with some research revealing increases that correlate with dosage variation. However, there is a pattern that indicates a return to normalcy over time, emphasizing the complexities of radiation's genetic impacts. Contrary to earlier assertions, research has not shown a conclusive relationship between Down's syndrome and the Chernobyl disaster, emphasizing the significance of rigorous methodology in examining such associations.

VII. Mental Health and Psychological Effects

The Chernobyl tragedy had a long-lasting impact on the afflicted areas, causing a significant drop in social cohesiveness and overall well-being. While a variety of health problems have arisen following the tragedy, not all are directly related to radiation exposure. Rather, the long-term pressures, both physical and psychological, caused by the disaster have had a considerable impact on many non-cancer health conditions. The aftermath is characterized by a widespread deterioration of public faith in authority, notably in nuclear power problems. This failure in communication, along with fears about radiation's long-term effects, has sparked considerable worry and fury. Despite multiple studies confirming psychological symptoms in impacted individuals, these findings highlight the disaster's larger societal consequences rather than the acute medical impacts of radiation exposure.

Fig6: victims' monument in Kiev, Ukraine
Source: NBC News
https://media-cldnry.s-nbcnews.com/image/upload/t_fit-1240w,f_auto,q_auto:best/msnbc/Components/Photos/040426/0

Within the former Soviet Union, the Chernobyl nuclear plant tragedy coincided with a watershed moment defined by the emergence of "glasnost" and "perestroika." This age of increasing openness and change coupled with widespread disenchantment and an increase in anti-government sentiment, allowing for the public airing of previously suppressed concerns. Against an environment of financial difficulties and nationalist zeal, the Chernobyl disaster crystallized popular resentment, embodying the previous regime's shortcomings and fuelling anti-nuclear sentiment alongside larger nationalist movements.

Local knowledge frequently overshadowed official statements during a time of increased mistrust of authority, escalating popular unease. Although there was some immediate respite from the Soviet government's attempts to allay anxieties through assessments by foreign experts, the general sense of tension and anxiety persisted. The calamity left a lasting influence on society as social unrest, economic hardship, and mass displacement all combined to strain communal relationships even further. Even though there were few health consequences outside of the former Soviet Union, the Chernobyl disaster stoked anti-nuclear sentiment and reduced public confidence in government information sources, highlighting the need of open communication and public participation in decision-making processes.

VIII. Environmental Consequences

The Chernobyl tragedy resulted in large radionuclide discharges, including radioactive gases, aerosols, and fuel particles, that lasted 10 days after the explosion on April 26. The overall emission of radioactive chemicals was approximately 14 EBq, including major contributions from iodine-131, 137Cs, 90Sr, and plutonium radioisotopes. Noble gasses accounted for around half of the overall discharge. The resulting radiation reached more than 200,000 square kilometers of Europe, with 137Cs levels exceeding 37 kBq m-2. Precipitation patterns varied, with higher amounts seen when polluted air masses met with rainfall. While most short-lived radionuclides have decomposed since the disaster, 137Cs poisoning is still a major issue for decades to come, which will be followed by 90Sr. Plutonium isotopes and americium-241 are going to stay in the long run, but at quantities that are not considered radiologically relevant.

Fig6: cleanup of the area
Source: National Geography
https://i.natgeofe.com/n/0ad8ffda-77fe-4173-a3de-526339a56080/01-chernobyl_3x2.jpg?w=718&h=479

Radionuclides were most commonly deposited in metropolitan areas on open surfaces such streets, parks, lawns, and building facades. At first, moist weather raised concentrations on horizontal surfaces like soil plots and lawns, whereas dry conditions led to higher levels on trees, shrubs, and rooftops. Interestingly, rain increased the quantity of 137Cs near homes by carrying radioactive material from rooftops to the ground. Although evacuations helped reduce the risk, major external doses might have happened in places like Pripyat and the nearby towns as a result of the first deposition. Even Nevertheless, exposure to radiation varies in other metropolitan locations as well, albeit to a lesser extent because to wind, rain, and human activities like transportation and cleaning. Since 1986, surface pollution has significantly decreased, nevertheless, secondary contamination of sewage systems and sludge storage has surfaced. At the moment, air dosage rates above solid surfaces in the majority of polluted communities have recovered to levels seen before to the accident, increased levels are still present in parks and gardens throughout Belarus, Russia, and Ukraine.

Right after the Chernobyl disaster, surface deposits of radionuclides had a significant influence on agricultural plants and animals, raising urgent worries about radioiodine absorption through milk, especially among youngsters in Belarus, Russia, and Ukraine. While direct deposit dominated the early phase, subsequent absorption of radionuclides via plant roots in soil, particularly cesium isotopes such as 137Cs as well as 134Cs, became substantial, continuing beyond the disintegration of 134Cs and creating ongoing issues in impacted regions. Despite an initial reduction in move to vegetation and animals, recent years have seen little more decline, along with slow decreases in radiocaesium content in foodstuffs, highlighting the long-term significance of 137Cs in causing human internal dose and justifying went on environmental cleanup efforts in particular areas with raised pollutants levels.

Forests and mountainous regions absorbed considerable amounts of radiocaesium, resulting in chronically high levels of contamination in forest food products such as mushrooms, berries, and wildlife. This ongoing pollution has resulted in persistently high exposure levels, exceeding intervention criteria in several countries, notably harming people depending on forest foods in Belarus and Russia. The relevance of forests in contributing to radiological exposures has expanded over time, with modest decreases in contamination levels projected as 137Cs migrate below in soil and degrade physically. The accident's influence on plant and animal life in limited regions around the release point resulted in immediate negative consequences, including increased mortality and reproductive losses. However, no acute radiation-related consequences have been documented outside of the Exclusion Zone. As exposure levels naturally decreased owing to radionuclide decay and migration, biological populations started to recover from acute radiation impacts, with population viability being significantly recovered within just a few years through reproduction and immigration from less damaged regions. The suspension of human operations inside the Exclusion Area has aided in the recovery of injured biota, converting the region into a one-of-a-kind biodiversity refuge despite the accident's initial negative consequences.

IX. Economic Impacts

The Chernobyl accident had a significant and wide-ranging economic impact, with both direct and indirect effects that placed a heavy financial burden on the impacted areas. In the early years after the disaster, the destruction of fixed assets, the decline in agricultural production, and the large-scale investments made in recovery and mitigation efforts accounted for nearly 9.2 billion roubles in direct losses. These expenses, which were mostly covered by the state budget, highlighted how expensive it would be to deal with the disaster's immediate effects. However, the economic consequences went beyond these short-term costs, since indirect losses put a heavier and longer-lasting strain on the impacted economies. Once a crucial industry, agriculture faced enormous hurdles from polluted soils and declining consumer confidence, which resulted in a sharp decline in agricultural output and market disruptions. Once a source of income, the tourist sector was severely damaged as safety fears and stigma turned off travelers, which led to a downturn in the local economy for those towns.

In addition, there was a significant burden on public health systems due to the rise in the need for medical attention and rehabilitation programs for illnesses linked to radiation exposure and psychological stress. Long-term health effects, such as increased cancer rates, put a continuous financial strain on healthcare systems and made further investment in specialist treatment necessary. The impacted countries looked for outside support to deal with the complex economic issues brought on by the calamity. Working together and pooling resources were crucial to reducing the negative economic effects and assisting the impacted areas in their efforts to recover. The economic damages caused by the Chernobyl disaster may be lessened with coordinated efforts and successful international collaboration.

The impact of the 1986 Chernobyl tragedy has been catastrophic, with projected expenses totaling $700 billion over the last three decades, according to Jonathan Samet, an internationally recognized expert in preventive healthcare at USC's Keck School of Medicine. These costs, based on a thorough examination of the literature, highlight the catastrophe's deep and long-term impact. Surprisingly, the majority of these charges are ascribed to health-related repercussions, which outweigh even the direct costs associated with the nuclear plant. This financial burden goes far beyond current expenses, including a lifetime of healthcare demands and even affecting future generations. Among the numerous long-term consequences, cognitive problems such as depression stand out as particularly prevalent and expensive.

X. Lessons Learned from Chernobyl

The Chernobyl tragedy in 1986 was an unprecedented moment, exposing fundamental flaws in emergency preparedness and radiation protection. It provided as a sharp reminder of the importance of strong infrastructure and well-defined standards for properly managing such catastrophic catastrophes. The first reaction showed national authorities' lack of readiness, as they struggled to make appropriate judgments in the midst of the growing crisis. The lack of specified criteria and delineations resulted in fragmented decision-making, emphasizing the need for distinct boundaries of authority and cooperation. One of the most important lessons learned from Chernobyl was the need to set up long-term infrastructures, including as monitoring networks, intervention teams, and communication systems, in order to quickly adopt safety precautions. Since procedures like iodine distribution and evacuation were too complicated to carry out efficiently during a crisis, proactive logistical preparation became essential. In order to ensure a coordinated response, it was also evident that emergency plans needed to incorporate protocols and intervention levels that had been agreed upon worldwide.

The disaster's transboundary character emphasized how crucial international collaboration is for emergency preparedness and response. Organizations such as the European Commission (EC) and the International Atomic Energy Agency (IAEA) have created agreements for mutual assistance and early reporting of nuclear accidents. These agreements facilitate the sharing of information and resources among affected nations. International mechanisms for coordination, information sharing, and communication in nuclear crises were created in the wake of Chernobyl. Enhancing public communication and decision-making during nuclear emergencies was the goal of initiatives like the International Nuclear Event Scale (INES) and the European Community Urgent Radiological Information System (ECURIE).

XI. Advancements in Reactor Design after incident

The 1986 Chernobyl tragedy provoked a major reevaluation of reactor design and safety procedures, resulting in substantial advances in nuclear technology across the world. Following the disaster, numerous major design improvements and innovations were implemented to improve reactor safety and prevent such mishaps in the future.

All existing RBMK reactors have undergone considerable upgrades to solve their limitations. Originally, these reactors featured a design defect that allowed the nuclear chain reaction and power production to spike if cooling water was lost or converted to steam, unlike most Western reactor designs. This fault resulted in an uncontrolled power spike, which destroyed Chernobyl Unit 4. To reduce this danger, considerable alterations were made to the control rods, including as the insertion of neutron absorbers and an increase in fuel enrichment from 1.8% to 2.4% U-235. These improvements dramatically improved reactor stability, especially at low power levels. Furthermore, automatic shutdown systems now respond more quickly, and overall safety elements have been enhanced. Furthermore, automatic inspection equipment has been installed, which improves safety precautions. According to research by a German nuclear security body, the possibility of a replay of the 1986 Chernobyl tragedy has been practically eliminated as a result of these improvements. Since 1989, major worldwide collaboration initiatives have been ongoing to improve nuclear safety and share knowledge. More than 1000 nuclear engineers from the former Soviet Union have visited Western nuclear power facilities, with reciprocal trips taking place. More than 50 twinning agreements between East and West nuclear reactors have been developed thanks to organisations including the World Association of Nuclear Operators (WANO). These activities aim to promote collaboration and knowledge exchange among nuclear power plant operators globally. Furthermore, various worldwide projects were launched after Chernobyl to increase nuclear safety standards. The International Atomic Energy Agency (IAEA) led safety assessment initiatives targeted to certain types of Soviet reactors, allowing operators and Western engineers to work together to improve safety. These attempts have been bolstered by finance agreements, with the Nuclear Safety Assistance Coordination Centre database revealing approximately $1 billion in Western contributions for over 700 safety-related projects in former Eastern Bloc nations. Furthermore, the approval of the Convention on Nuclear Safety in Vienna in June 1994 was a key result of international efforts to improve nuclear safety standards worldwide.

Fig7: Chernobyl Unit 2
Source: Science photo library

Using sturdy containment structures was an important part in improving reactor design. In order to prevent radioactive elements from leaking in the case of an accident, containment structures made of reinforced concrete and many levels of protection were integrated into new reactor designs. By being built to withstand powerful external pressures like explosions and earthquakes, these containment buildings reduce the chance of radioactive leaks into the surrounding environment. Additionally, emergency cooling systems were updated to guarantee prompt and efficient reaction to possible mishaps. Replicated emergency core cooling systems (ECCS) are a characteristic of new reactor designs that come online automatically in case of a loss of coolant accident (LOCA) or other emergency. By keeping the reactor core sufficiently cooled, these ECCS guard against fuel overheating and meltdown.

One of the biggest changes was the adoption of reactor designs that are intrinsically safer. Passive safety elements, which depend on natural processes like gravity or natural circulation to safely shut down the reactor in case of an emergency, are given priority in these designs. To lessen the effects of accidents, for instance, many contemporary reactor designs, such the European Pressurized Reactor (EPR) and the Advanced Boiling Water Reactor (ABWR), have redundant safety mechanisms and passive cooling systems. Following Chernobyl, there was an emphasis on building Generation III and III+ reactor designs, which provide increased safety measures and higher performance over prior reactor models. These reactors often have sophisticated control systems, improved fuel designs, and stronger containment buildings to survive a variety of external disasters such as earthquakes, floods, and terrorist attacks. Examples of Generation III reactors are Westinghouse Electric Company's AP1000 and General Electric's ESBWR (Economic Simplified Boiling Water Reactor). The incorporation of passive safety mechanisms in reactor designs was another significant innovation that came about following the Chernobyl accident. In the case of an accident involving the loss of coolant or other situations, these devices offer an extra line of defense since they function without the need for human involvement or external power. Systems for passive containment cooling, passive shutdown, and passive residual heat removal are examples of passive safety systems. Fuel technology advanced significantly after Chernobyl, with the development of better fuel assembly and cladding materials. New fuel designs provide more safety measures, such as improved heat transmission and corrosion resistance. Furthermore, improved cladding materials reduce the danger of fuel failure and the release of radioactive elements into the reactor coolant system.

Apart from the technological progress, the nuclear sector also benefited from improved operator training programs and a strong safety culture. Operators must complete extensive training and certification in order to guarantee that they are qualified to handle crises and avert mishaps. Initiatives to foster a safety culture encourage candid communication, ongoing education, and a pro-active attitude to recognizing and resolving safety issues. Stricter safety guidelines and monitoring protocols were implemented by regulatory bodies worldwide to guarantee the secure functioning of nuclear power plants. In order to address new safety concerns and take into account the lessons learnt from the tragedy, regulatory frameworks were revised. Regular audits, evaluations, and inspections are carried out to ensure that safety rules are being followed and to encourage further advancements in nuclear safety.

XII. Response, Recovery Efforts and Chernobyl now

After the Chernobyl tragedy in 1986, initiatives were undertaken to progressively shut down the facility while guaranteeing safety and meeting electricity demands. During the early 1990s, around $400 million was spent in improving the safety of the surviving reactors. Unit 2 had to be shut down on 1991 due to the turbine hall fire, while Unit 1 was decommissioned in 1997. To address energy shortages, Unit 3 remained operational until December 2000. Despite the hazards, intensive radiation monitoring assured the safety of the almost 6000 daily employees, who were transferred with loved ones in Slavutich, a new town 30 kilometers from the facility following Pripyat's evacuation. Ukraine's reliance on Russia for energy, especially nuclear fuel, affected choices about Chernobyl's shutdown. Plans to shut the remaining reactors by 2000 were postponed, resulting in the commencement of development for Khmelnitski Unit 2 and

Rovno Unit 4 ('K2R4') in 2004, which was financed domestically. This gradual shutdown highlights the complicated interaction of safety, economic concerns, and geopolitical pressures in the shift toward nuclear power.

The Chernobyl nuclear facility was taken over by Russian forces on February 24, 2022, which resulted in a rise in the exclusion zone's gamma radiation dosage rates. The plant's health remained similar, but the spike was linked to air pollution and soil disturbance from military operations. Later, on March 9, there was a loss of grid connection, but the operation was maintained by backup diesel generators. The International Atomic Energy Agency (IAEA) guaranteed adequate heat removal from stored spent fuel in spite of reservations. Professor Geraldine Thomas stressed that the fuel bundles produced very little heat and that any possible radiation leakage was limited to the immediate vicinity.

The Chernobyl Unit 4 reactor was hurriedly housed in a concrete bunker following the disaster. However, the structure proved insufficiently strong, containing around 200 tons of extremely radioactive material. To address this persistent threat, the latest New Safe Confinement (NSC) construction was finished in 2017. This massive arch, which stands 110 meters tall, 165 meters long, and spans 260 meters, was built close to the site and then hauled in on tracks. The NSC, which has internal cranes and a lattice framework of tubular steel components, is the biggest transportable land-based structure ever created. Its hermetically sealed construction allows for the remote disassembly of the original shelter and ultimate evacuation of fuel-containing elements from the reactor building. The NSC facilitates this critical step in removing the nuclear threat from the site by allowing for remote handling of dangerous items with little worker exposure. The project, which is supported by the Chernobyl Shelter Fund and the European Bank for Reconstruction and Development's Nuclear Safety Account, has garnered significant foreign donations totaling billions of euros. Despite considerable funding, more resources were needed to properly pay the project's expenditures.

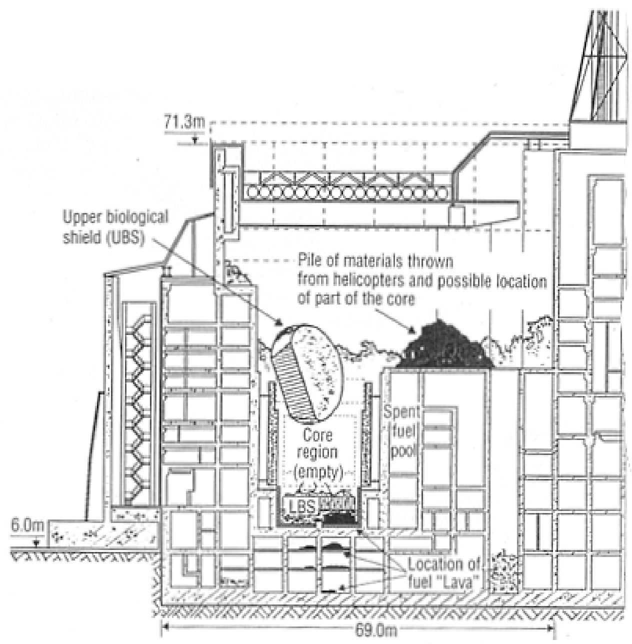

Fig8: damaged Chernobyl unit 4 reactor
Source: World Nuclear association
https://world-nuclear.org/getmedia/439e52ac-8997-

To guarantee safe storage and eventual disposal, the Chernobyl Nuclear Power Plant's handling of spent fuel and radioactive waste has undergone considerable advancements. Most of the spent fuel from units 1-3, which was formerly kept in cooling ponds within each reactor unit, has been combined into the intermediate spent fuel storage facility pond (ISF-1), enabling for the reactors to be decommissioned under less stringent guidelines. But difficulties encountered during the building of the ISF-2 radioactive waste disposal facility resulted in the 2007 cancellation of the original agreement with Framatome. Nonetheless, Holtec International took charge as the contractor in 2007, and the ISF-2 facility will be completed in January 2020. This cutting-edge facility, with a dry storage capacity of 21,217 RBMK fuel assemblies, includes a processing plant capable of treating 2500 fuel assemblies per year, paving the way for the long-term handling of radioactive waste at the Chernobyl site.

After the shutdown of the final Chernobyl reactor in December 2000, SSE ChNPP was created in mid-2001 to administer the site and oversee decommissioning works. With a mandate to eventually decommission all Ukrainian nuclear facilities, SSE ChNPP operates on a four-stage decommissioning plan published by the Ukrainian government in January 2008.

XIII. Conclusion

The devastating effects of nuclear catastrophes are still vividly remembered in the wake of the 1986 Chernobyl nuclear disaster. Significant efforts have been undertaken over the years to reduce the threats to the environment and public safety presented by the damaged reactor, including the building of many containment structures including the New Safe Confinement (NSC). Financial backing and international collaboration have been essential in financing cleanup initiatives such as the NSC and the Interim Used Fuel Storage Facility (ISF-2). In addition, decommissioning plans have been created to securely manage remaining reactors and radioactive materials, demonstrating a commitment to long-term security and environmental preservation. Regardless of the hurdles and failures experienced along the road, these activities represent a collaborative effort to confront Chernobyl's legacy and protect the next generation from similar disasters.

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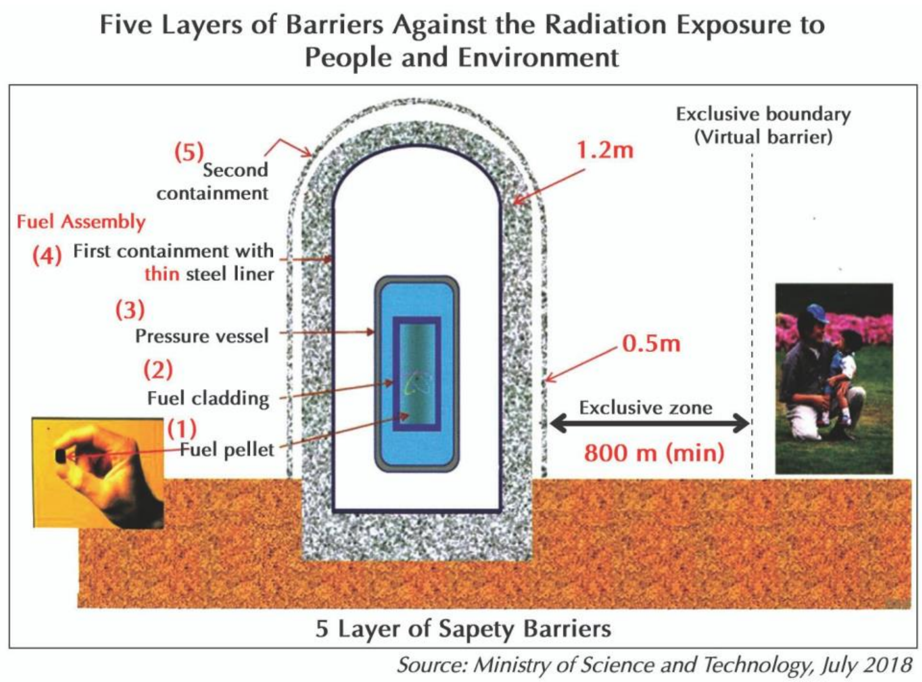
- ***How the safety and other feature are improved in VVER200 in Rooppur Nuclear Power Plant.***

The Rooppur Nuclear Power Plant (RNPP) is a recent addition to Russia's VVER (Water-cooled Water-moderated Power Reactor) reactor plant, employing AES-2006 (VVER-1200, V-392M) technology and adding site-specific safety measures. The design of both Unit 1 and Unit 2 reactors is based on the VVER-1200 reactor plant, which has been enriched by extensive expertise gained from the design, equipment manufacturing, construction, and commissioning experiences of Novo Voronezh NPP-II, as well as insights gained from the operation of the most modern VVER reactors both in Russia and around the world. High standards are upheld in the engineering solutions and design documentation, which are based on the application of current Russian regulations, standards, and international agency recommendations along with adherence to domestic regulatory requirements and considerations of site-specific seismic and climatic conditions. The integration of state-of-the-art safety measures and technical improvements is ensured by this methodical approach, which promotes trust in the RNPP's dependability and resilience against a range of possible threats and obstacles.

The VVER-1200 reactors used in the Rooppur Nuclear Power Plant have numerous significant safety improvements over earlier generations of nuclear reactors. These developments are mostly focused on passive safety systems, which work without the need for external intervention or power supply during an emergency. These systems, which rely on natural processes such as gravity and condensation, increase the plant's resistance to mishaps. Furthermore, the VVER-1200's control and instrumentation systems have been upgraded, allowing for more accurate monitoring and management of reactor activities. major Accident Management Systems (SAMS) improve safety measures by providing techniques for mitigating the effects of major catastrophes. Enhanced fuel designs and containment structures offer layers of safety, lowering the chance of fuel failure and limiting the emission of radioactive material. Furthermore, thorough emergency response plans that are regularly updated in accordance with past experiences and changing safety requirements guarantee prompt and efficient responses in the case of any unanticipated events. When taken as a whole, these safety feature enhancements represent a major advancement in guaranteeing the safe and dependable operation of the Rooppur Nuclear Power Plant and emphasize the dedication to upholding the strictest nuclear safety regulations.

The Rooppur nuclear power station will only be used to generate electricity, with no reactor experiments allowed. Lessons learned from previous nuclear mishaps, such as the Three Mile Island and Chernobyl catastrophes, as well as numerous minor occurrences, have helped to improve both reactor safety and operational practices throughout time. As a nuclear power plant operator, Bangladesh will join the World Association of Nuclear Operators (WANO), which was founded in 1989. This participation implies a commitment to maintaining strict safety requirements established by international benchmarks that apply to all power reactors worldwide. Rooppur is required to adhere to these safety norms strictly. Notably, no mishaps involving notable emissions of radiation into the atmosphere have occurred since the Chernobyl tragedy. The Pressurized Water Reactor (PWR) nuclear power facility at Rooppur is expected to operate safely because to improved design elements, dependable safety standards that include both active and passive safety devices, and extensive operator training programs. An catastrophe similar to the Rooppur Chernobyl Unit 4 incident is considered extremely unlikely in any case.



Source: Ministry of Science and Technology

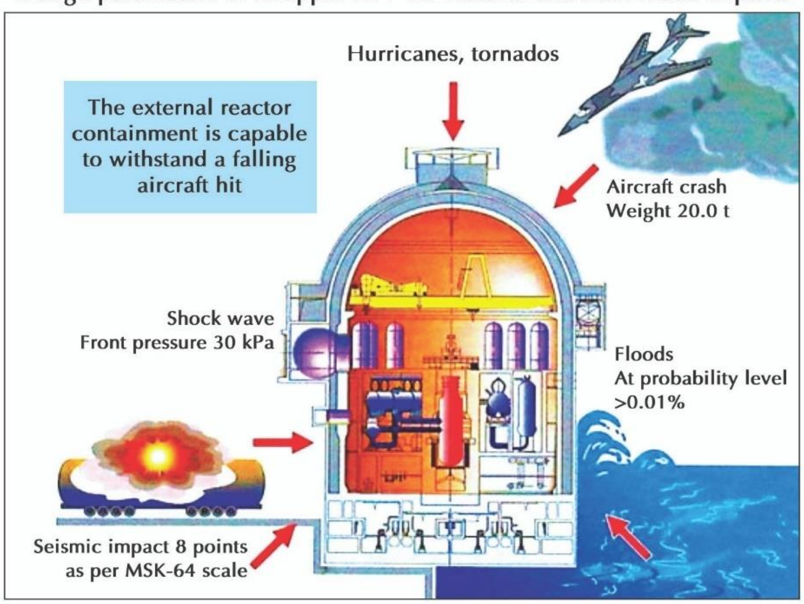
Safety Barriers:

The safety system of the RNPP is largely based on active safety systems, which include both normal and emergency power supply methods. Passive safety measures are also used to prevent or lessen the effects of serious accidents. These passive systems function independently, without the need for human involvement or external power sources. In the case of a serious disaster caused by excessive power loss, such as a grid failure similar to the Fukushima NPP catastrophe, the RNPP will safely shut down for up to 72 hours without requiring external help or off-site power supply. Strong safety precautions are highlighted by the plant's blend of active and passive safety systems, which have 2-4 times the efficacy and diversity. Emergency and planned cooling protection, high-pressure emergency injection, emergency boron injection, emergency feedwater systems, emergency gas removal, pressure protection for primary and secondary circuits, containment isolation, spray systems, ventilation, and critical power supply systems are all included in active safety systems. Quick boron injection, hydro-accumulators, passive containment heat removal, passive steam generator heat removal, hydrogen concentration monitoring, hydrogen passive recombination within containment, molten corium trap, and cool-down systems are examples of passive safety devices. In order to guarantee continuous operations in the event of unanticipated situations, emergency power supplies and standby diesel power systems are also in place.

Safety Systems from Natural and Manmade Disasters:

The Rooppur Nuclear Power Plant (RNPP) has special safety elements that were precisely built to withstand natural and man-made disasters, guaranteeing resilience in any adverse situation. Extensive safety precautions are adapted to the plant's location, taking into consideration seismic design characteristics and a variety of natural phenomena such as cyclones, tornadoes, floods, severe temperatures, and winds, as well as man-made risks. The project site has undergone a thorough engineering-geological investigation, which has resulted in the installation of the required equipment and the creation of seismic-geotectonic, aero-meteorological, and engineering-hydro-meteorological models. The safe shutdown and design basis earthquake parameters are set at 8 and 7 points on the MSK-64 scale, respectively, to tolerate earthquakes of substantial intensity.

Design parameters of Rooppur NPP for Natural and Man-made Impacts



Source: Ministry of Science and Technology

The maximum probable flood (MPF) scenario, which includes a wide range of hydrological events with a 0.01% probability frequency, such as potential impacts from precipitation, fluctuations in the Bay of Bengal's water level, effects of global climate change, and the hypothetical failure of the Farakka dam, was determined with the help of hydrological, hydraulic, and morphological studies. Engineering flood safeguards are carefully included into the layout, and catch drains make sure that surface water is removed. Comprehensive engineering and climatic studies on extreme winds, temperatures, and other climatic parameters have been made possible by considerations of the tropical climate zone and extreme weather. Climate needs have influenced the design parameters for ventilation systems, plant cooling capacity, fluid coolant usage, supply pipeline diameters, air conditioning systems, and architectural layouts. With systems in place for chemically demineralized water preparation, cooling towers, and an auxiliary power supply, the design also takes into account the quality and physio-chemical qualities of Padma River water. This ensures the plant's operating stability under a variety of environmental situations.

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