Chernobyl Disaster

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Introduction

The Chernobyl disaster occurred in 1986 when I was an engineering student. There was little information released about it at the time because it took place within the secretive society of the Soviet Union. To most Americans, the Soviet Union was a distant enemy. However, the event turned out to be catastrophic, causing immediate deaths, contaminating a large area, and leading to long-term illnesses among many Soviet citizens, all while their government lied to both its people and the world. Additionally, the disaster played a role in the eventual collapse of the Soviet Union.

The disaster began with a safety test that ultimately resulted in the destruction of the reactor. It started at 1:23 AM on April 26, 1986, in reactor 4 of the Vladimir I. Lenin Nuclear Power Plant at Chernobyl. It is estimated that approximately 9 million people in Ukraine, Belarus, and Russia were directly affected. The long-term release of radioactivity was over 200 times higher than the radioactivity released by the bombs dropped on Hiroshima and Nagasaki at the end of World War II.

The causes of the disaster can be attributed to a combination of human error, a lack of safety mindset, and a flawed reactor design. In the Soviet Union, nothing was done without the approval of Moscow, so situations were not handled at a local level as they are in the United States. In other words, the decision-making process worked from a national level down to the local level, whereas in the United States, it works from a local level up to the national level. This difference in approach is crucial for effective emergency management.

The consequences of the disaster led to the evacuation of 400,000 people, many of whom were permanently displaced. Approximately 200,000 square kilometers of land were contaminated by radioactive Caesium-137 above the intervention level of 37,000 Bq/m2. Additionally, forty percent of Europe's surface area had contamination levels above 4,000 Bq/m2. This radioactive contamination is expected to persist for centuries.

The health consequences of the accident remain uncertain, with conflicting research results. Official accounts estimated around 4,000 cancer deaths in Belarus, Ukraine, and Russia. However, the IAEA/WHO predicted 9,000 deaths, and other studies suggest even higher numbers. One publication even suggests that the number could be as high as 900,000.

People Involved

It would be impossible to discuss everyone involved in the disaster and cleanup. Therefore, only the main characters will be introduced.

Anatoly Stepanovich Dyatlov
Anatoly Dyatlov was the deputy chief engineer who supervised the overdue safety test on reactor number 4. He was a graduate of the Moscow Engineering and Physics Institute and had previously worked at a shipbuilding plant that installed reactors into nuclear submarines. During a nuclear accident, he received a radiation dose of 100 rem. Unfortunately, one of his sons died of leukemia at the age of nine.

In 1973, Dyatlov moved to Pripyat to work at the Chernobyl Nuclear Power Plant, originally named the Vladimir Lenin Nuclear Power Plant. He held a senior managerial position and was responsible for overseeing Units Three and Four.

Dyatlov was known for his Theory X management style. He was authoritarian and unforgiving, projecting an image of infallibility. He frequently cursed at staff who did not precisely follow his orders. While some of those he supervised respected his knowledge of reactors, many others feared and despised him.

On the night of the test, Dyatlov was sleep-deprived and ill-tempered, as was often the case. Leonid Toptunov, a reactor engineer, made a mistake after taking over control during the midnight shift. Despite Toptunov's concerns and adherence to established safety protocols, Dyatlov insisted on continuing the test.

Following the accident, Dyatlov was admitted to the Pripyat hospital after receiving a radiation dose of 390 rem. Initially, he refused treatment, claiming that he only needed sleep. He was later transferred to Hospital 6 in Moscow. Although his symptoms improved after a few days, the delayed effects of radiation ultimately worsened his condition. During his time in the hospital, he discussed possible causes of the accident with Akimov and Toptunov, but they were unable to identify a definitive cause. Eventually, Dyatlov did recover.

Dyatlov and several others, including Nikolai Fomin, Viktor Bryukhanov, and three others, were criminally charged for failing to follow safety regulations. Dyatlov maintained his defiance throughout the subsequent show trial, which began on July 6, 1987, at the Palace of

Culture in Chernobyl. He argued that the operators were not solely responsible for the accident, but the court did not consider design flaws in the reactor. On July 30, 1987, it was reported in the Russian press that Dyatlov and all other defendants were found guilty. He was sentenced to ten years in a labor camp (prison) but was released in 1990 due to failing health caused by radiation exposure. He ultimately died of bone marrow cancer in 1995, most likely resulting from radiation poisoning from the accident.

Viktor Bryukhanov

Viktor Bryukhanov was the builder of the Chernobyl NPP. He received a degree in electrical engineering from the Energy Department of the Tashkent Polytechnic University in 1959. He was appointed as the head of the Chernobyl nuclear project at the age of 34. At the time of the accident, he was expecting news of a promotion that would send him to Moscow.

In 1970, he was offered the assignment of building an atomic power plant on the banks of the Pripyat River in Ukraine. During the construction, there were missed deadlines due to a tight schedule, lack of construction equipment, and defective materials. After three years, the plant had not been completed. He offered his resignation, but it was torn up by his party-appointed supervisor in July 1972. The first reactor finally went online on August 1, 1977.

Bryukhanov was described by sources as soft-spoken and well-liked by his staff. However, he was also overworked and bullied by his bosses in the Communist Party. For example, he was forced to cut corners and falsify the books to meet quotas. Bryukhanov had to preside over the response to fuel element damage in reactor 1 on September 9, 1982. During the incident, contaminated steam was vented into the atmosphere. He also helped cover up the partial meltdown of reactor number 1. In 1983, he signed off on the launch of reactor number 4, even though a required safety test had not been completed.

He was notified of the April 26, 1986 accident by the head of the chemical station. When he arrived, he ordered all authorities to meet in the nuclear bunker in the basement of the administration building of the plant. After attempting to contact the shift supervisor of reactor 4, he reached out to his superiors in Moscow and local Communist Party officials.

Due to the lack of high-range dosimeters, Bryukhanov and Fomin instructed the operators to restore and maintain a coolant supply, unaware that the reactor had been destroyed. He contacted Vladimir Marin, who was in charge of nuclear matters for the Communist Party, to report the accident and assure party officials that the situation was under control. Despite

witnessing the damage to the reactor, he continued to maintain that the core was intact. This assumption may have been made because they only had low-range dosimeters and chose to disregard the graphite scattered on the ground.

Bryukhanov was ordered to Moscow for a Politburo meeting on July 3, 1986, during which the causes of the accident were discussed. He was accused of mismanagement, and it was determined that operator error was the primary cause of the accident. After the meeting, he was expelled from the Communist Party of the Soviet Union. The true cause of the accident was classified by the KGB, and he was officially charged on August 13, 1986, and imprisoned. He received a 10-year prison sentence but was released early for good behavior after serving half of his sentence. He maintained that there was nothing wrong with the reactors and that there was only a technical error in reactor number 4. Many considered him a scapegoat.

Leonid Toptunov

Leonid Toptunov was the reactor control engineer for reactor number 4 on the night of the disaster. He was a graduate of the Moscow Engineering and Physics Institute. He began working at Chernobyl in March 1983 after his graduation, where he served as a unit control engineer. While studying the reactor documentation, he made an observation to his friend Sasha Korol about the control rods. He pointed out that under certain circumstances, the control rods could accelerate the reaction instead of slowing it down. Despite being a senior reactor operator for only two months, he had never taken the reactor through the shutdown process.

Toptunov was working alongside Aleksandr Akimov. Before starting the test, Toptunov skipped a step in the process of assuming control, which caused the reactor power to fall far below the minimum required for the test. According to his training, he believed the test should be aborted. However, Anatoly Dyatlov threatened Toptunov and forced him to increase the power to the level required for the test. This decision left the reactor vulnerable to a runaway reaction. The AZ-5 button was pressed to abort the test after 36 seconds. Due to a design flaw in the reactor, the descending control rods briefly accelerated the nuclear reaction (due to graphite tips), leading to the reactor explosion.

After the explosion, Toptunov worked with Akimov to manually open water valves in an attempt to increase water flow to the reactor. During this time, they both started experiencing symptoms of acute radiation syndrome. They were initially taken to the infirmary and then transferred to the Pripyat Hospital before being moved to Moscow Hospital 6. Toptunov was

exposed to 1,300 rems during the accident. He ultimately died of acute radiation poisoning on May 14, 1986.

Nikolai Fomin

Nikolai Fomin was the chief engineer. He began working at Chernobyl in 1972. He was the person who approved the turbine safety test. He also participated in the cleanup efforts after the accident. He was a member of the Communist Party of the Soviet Union but was expelled from the party following the accident. He was arrested and attempted suicide while awaiting trial. The trial was postponed due to his suicide attempt. During the trial, he blamed the operators for deviating from the test plan. He was ultimately found guilty and sentenced to 10 years in prison.

While in prison, Fomin received psychiatric treatment. He was released from prison early and transferred to a psychiatric hospital for further treatment. After his release, he worked in the field of nuclear power at the Kalinin Nuclear Power Plant. He retired in 2000.

Valery Legasov

Valery Legasov was the director of the Kurchatov Institute for Nuclear Energy. The Kurchatov Institute was where the RBMK reactors were designed. He was a radiochemistry specialist and the head of the scientific team that was sent to Chernobyl immediately after the accident on April 26, 1986. Legasov became the public face of the effort to contain and investigate the disaster. He also led the Soviet delegation that presented the research report to the congress in Vienna. Legasov graduated from the Mendeleev Moscow Institute of Chemistry and Technology in 1961, where he learned about nuclear fuel processing, handling, and disposal. He obtained his doctorate in chemistry in 1972 at the Kurchatov Institute for Nuclear Energy.

Legasov was a staunch believer in Communism and resided in a villa near his office. He learned about the accident at a Party meeting on the morning of April 26, 1986. He was ordered to join a government commission and was flown to Chernobyl to take control of the emergency situation. At the airport, he met with Boris Shcherbina, the head of the commission investigating the incident. Legasov was put in charge of containing the radiation when they arrived in Pripyat. He supported the immediate evacuation of Pripyat, a decision that Shcherbina eventually approved.

Legasov managed the efforts to extinguish the reactor fire. He admired Boris Shcherbina's leadership, particularly his ability to understand the specialists. Legasov himself had been over

the reactor many times but was scolded for taking too many personal risks due to his vital role in the operation. He wanted to establish an information group to collect and distribute accurate information, but this initiative never materialized. He noticed that the press often interviewed the most famous person rather than the most knowledgeable, leading to the introduction of many inaccuracies.

After the first governmental commission returned to Moscow, Shcherbina asked Legasov to stay behind. Legasov was replaced in the formal hierarchy by his professional rival, Evgeny Velikhov, who was concerned about the possibility of the reactor melting through the concrete pad and into the ground, similar to what was depicted in the movie "The China Syndrome."

Legasov was impressed by the KGB operation but not by the Civil Defense group, which he considered to be in disarray. He was also concerned about the lack of safety information provided to the population.

On May 5, 1986, Legasov was called back to Moscow to meet with the Politburo, including Mikhail Gorbachev, and provide a progress report. He described the various meltdown scenarios and agreed with a plan to tunnel under the reactor to provide cooling. Legasov assured Gorbachev that the extent of the contamination was understood and not a threat to other countries. Legasov also provided a timeline to Gorbachev around May 9th or 10th to prepare for an interview.

When Legasov returned for the second time, he was suffering from radiation sickness due to his prolonged exposure to Chernobyl. He was then tasked with compiling a report for the IAEA (International Atomic Energy Agency) about the causes and aftermath of the disaster. On July 3, 1986, Legasov attended a meeting of the Politburo, during which the causes of the accident and the flaws of the RBMK reactor were discussed. Gorbachev was furious and accused the designers of covering up problems in the nuclear industry. He criticized the Central Committee for excessive secrecy and lack of transparency. Gorbachev emphasized the importance of openness and maximum information sharing with the world, as the West already knew about the state of affairs. Legasov fell short of Gorbachev's vision when he did not fully disclose the design flaws during his subsequent presentation in Vienna. However, he did mention in the Politburo meeting that he had been warning about safety problems in the RBMK reactor for years.

The first draft of Legasov's report was not well-received by some members of the Central Committee. One minister sent it to the KGB and recommended prosecuting the authors. Legasov presented his report to the IAEA in Vienna in August 1986, although some details were censored by the Central Committee. The report was noted for its detailed and relatively open discussion of the tragedy, including defects in the reactor and operator training. His five-hour presentation and report were considered a public relations win for the Soviets.

As a result of his presentation in Vienna, Legasov gained popularity in Europe, but many of his Soviet colleagues became envious. In the spring of 1987, he was denied membership in the Kurchatov Institute's Scientific-Technical Council. Legasov's friend, Vladimir Gubarev, criticized his colleagues, stating, "I felt like telling them that Legasov never left Chernobyl, but I didn't see you there."

Legasov was also the only member of his team from Chernobyl that did not receive the award “Hero of Socialist Labor”. Valery Legasov's story took a tragic turn. On the second anniversary of the Chernobyl disaster, on April 26, 1988, Legasov died by suicide. His death was a shock to his colleagues and the scientific community. Legasov left behind audio tapes in which he explained his reasons for taking his own life. In these recordings, he expressed his deep frustration with the government's handling of the accident and its unwillingness to address the underlying issues with the RBMK reactors. He also mentioned his concerns about the long-term effects of radiation exposure, both on himself and the people affected by the disaster.

Legasov's suicide brought attention to the failures and cover-ups surrounding the Chernobyl accident. It added to the growing public awareness of the scale of the disaster and the need for transparency in nuclear safety. Legasov's contributions to understanding the causes and aftermath of the Chernobyl disaster were later recognized, and he is regarded as a hero by many for his efforts to reveal the truth about the accident.

It's worth noting that while the character of Valery Legasov is portrayed in the HBO miniseries "Chernobyl," some aspects of his portrayal in the show, particularly regarding his interactions with other characters and the timing of events, are fictionalized for dramatic purposes. The show captures the essence of Legasov's role in the Chernobyl disaster but takes creative liberties in its depiction.

Boris Shcherbina

Boris Shcherbina was the head of the Soviet fuel and energy industries. He received an urgent message from Moscow while preparing to give a speech to workers in an oil field. He flew to Ukraine to take charge of the incident at Chernobyl.

Shcherbina was 66 years old and a master of the ways of the Soviet system, including its absurd quotas, unreasonable deadlines, and arbitrary rules. He was responsible for bringing the catastrophe under control and investigating its cause. Nothing could happen in the Exclusion Zone without his approval.

When he arrived at the scene after the explosion, he displayed the arrogance that we would expect from a Soviet official. He disregarded the need for personal radiation protection and dismissed calls for an immediate evacuation of Pripyet. It took 36 hours after the accident before the city was finally evacuated.

Building of the Chernobyl Plant and Early Operations

In 1970, construction began on the city of Pripyat, approximately two miles from the future site of the Chernobyl Nuclear Power Plant. Pripyat was one of the nine "atom towns" intended for employees of nuclear power plants. It was officially declared a city in 1979. Chernobyl is approximately 80 miles north of Kiev, Ukraine. Construction of the power plant began in March 1970.

Discussions took place in 1972 in Kiev regarding the type of nuclear power plant to be built at the Chernobyl site. Grigori Medvedev, the Deputy Chief Engineer for the Chernobyl site, proposed the construction of Pressurized Water Reactors (PWRs), and this proposal was supported by Viktor Bryukhanov, the director of Chernobyl. He stated to Aleksei Makukhin, the Ukraine Minister of Energy, that the RBMK reactor releases forty times more radiation than a PWR. An RBMK is a boiling water reactor. A scientist named Alekzandrov opposed this and stated that the RBMK-1000 was the safest and most cost-effective in terms of electricity production. As a result, they decided to build the RBMK pressure tube reactors.

The filling of the cooling water reservoir began in October 1976. The Chernobyl nuclear power plant started supplying power on September 26, 1977. The second reactor was ready to operate in 1978. In April of the following year, the plant reached its first milestone of generating 10 billion kilowatt-hours of electricity.

As early as 1977, there were indications that shortcuts were being taken during the construction of the reactors. A document released by the KGB in 2003 revealed that there were design deviations, as well as violations of construction and assembly. In 1979, the KGB possessed data indicating that design deviations and violations of construction and assembly technology were occurring at various points in the construction of unit number 2. It was reported that these violations could have led to accidents. A similar report was made regarding unit number 1, both of which were already in operation. A document dated 1984 noted deficiencies in the third and fourth reactor blocks and poor-quality equipment being sent from Yugoslav companies.

A partial core meltdown occurred in reactor number 1 in 1982. The reactor was quickly repaired and put back into service within months. The extent of the partial meltdown was not made public until 1985. Reactor number 4 at Chernobyl was completed in December 1983. It began operations on December 20, 1983, and was reported by the media on December 22,

1983. This was unusual, as there is typically a gap of approximately six months between the completion of construction and a plant becoming operational.

In April 1985, Anatoly Mayorets, the Minister of Energy, stated that information regarding any adverse effects caused by the energy industry on employees, people, and the environment was not suitable for publication in newspapers, radio, or television. Mayorets went further after the accident. On July 18, 1986, he decreed that his civil servants were forbidden from telling the truth to the media about the Chernobyl accident. He was allowed to keep his job, although he was reprimanded and warned about future conduct.

In February 1986, Vitali Sklyarov, who was the Minister of Power and Electrification of Ukraine, was quoted in Soviet Life magazine as saying, "The odds of a meltdown are one in 10,000 years. The plants have reliable controls that are protected from any breakdown with three safety systems." The following month, on March 27, 1986, a Ukrainian publication featured an article written by Ms. Lyubov Kovalevska, a Ukrainian journalist. She wrote that "substandard construction, workmanship, and concrete, along with thefts and bureaucratic incompetence, are creating a time bomb. The failures here will be repaid over the decades to come.”

The Safety Test and Explosion

A safety test set in motion the events leading to a meltdown. The preparation for the safety test began on April 25, 1986, and the test was to coincide with a maintenance shutdown. The test was designed to determine if, in the event of a power failure, the spinning turbines could produce enough electric power to keep the coolant pumps operating until the backup generators could generate the required power to run the main cooling pump (60 to 75 seconds delay). This was to bridge the brief time gap before the emergency generators took over.

This was the fourth attempt to perform the test. The initial test was carried out in 1982 and generated insufficient excitation voltage due to the failure to maintain the desired magnetic field after the turbine trip. The test was repeated unsuccessfully in 1984 after a modification of the electrical system. A 1985 attempt yielded no results due to an issue with the recording equipment.

This test was intended to run with preparation, followed by an electrical test that was scheduled before a maintenance shutdown. In the preparation phase, the reactor thermal power was to be reduced to between 700 MWt and 1,000 MWt to allow for adequate cooling. The steam turbine generator was supposed to run at normal operating speed during this test. Four of the eight main pumps were to be powered by the turbine, while the other four pumps were to be supplied with off-site power. After the preparation conditions were achieved, the steam supply to the turbine generator was to be closed off, and the reactor shut down. The voltage supplied by the winding-down turbine would be measured, along with the voltage and revolutions per minute of the circulating pumps being supplied by the turbine. Then, after the emergency generators reached full power, the turbine generator would continue winding down.

The operators began reducing the power of reactor number 4 on April 25, 1986, at approximately 1 AM. At approximately 2 PM, the reactor's emergency core cooling system was disabled to keep it from interfering with the test. It was around this time that the test was delayed to accommodate the power needs of the region during peak evening demand. Under normal conditions, the power would have been reduced to 30 percent, but the authorities refused to allow further reduction due to the need for electricity.

At approximately 11:10 PM, the operators received permission to continue with the test and the shutdown of the reactor. At this time, the less experienced night shift was on duty. They had fewer experienced operators and were not prepared for the test. They never received adequate

instructions on how to properly perform the test. A team of engineers who were present when the day shift left at 4 PM had become tired.

At midnight, Aleksandr Akimov took over as shift leader from Yuri Tregub. On April 26, 1986, at approximately 12:05 AM, an output power of 720 MWt was achieved. At approximately 12:28 AM, the power plunged from 1500 MWt to 30 MWt, far below the point at which the reactor is considered stable. The operators responded by removing most of the control rods, violating the plant's safety guidelines. The drop in reactor power convinced Akimov that the test should be aborted, but he was overridden by Anatoly Dyatlov (Deputy Chief Engineer).

The test was being supervised by Dyatlov. When the drop in reactor power occurred, he demanded that the test continue. He overrode the objection of Akimov and Toptunov and threatened to give the shift to Tregub, who stayed to help the night shift. He used intimidation to coerce them into attempting to increase the power.

A xenon buildup in the core hindered the raising of power. The power stabilized at approximately 1 AM, but at a lower level (200 MWt) than the prescribed 700 MWt due to the xenon poisoning of the reactor core. The plant supervisors ordered the test to proceed. The automatic emergency shutdown system and safety features were then turned off.

At approximately 1:19 AM, the operator blocked automatic shutdown due to low water level and loss of both turbines. This was based on concern that a shutdown would abort the test. The operator forced the reactor to 7 percent power by removing all but 6 control rods (15 were required). The reactor was not built to operate at this low power level. The RBMK-1000 reactor is unstable when the core is filled with water. The operator attempted to take control over the water flow, which was returning from the turbine manually. The operator was unsuccessful in getting the water flow corrected, and the reactor became more unstable.

The safety test officially began at 1:23:04 AM. An unexpected power surge then occurred. An operator named Leonid Toptunov responded at 1:23:40 AM. The temperature of the water became too high, and cavitation (bubbles) had reached the main circulation pumps. The coolant started boiling in the reactor, and the reactor power slowly increased. Toptunov reported the power issue to Akimov, who pressed the emergency shutdown button (scram or AZ-5). Some references indicate that it was Toptunov who pressed the AZ-5 button at Akimov's direction. Since they both died days later, we may never know exactly who and why. The control rods seized at a partial insertion of between 2 and 2.5 meters instead of the full depth of 7 meters.

Attempts to let them insert under their own weight failed. The reactor began making rumbling noises, and the control panel indicated pump failure and no water flow.

At 1:21 AM, before the explosions, the caps to the fuel channels were seen jumping in their sockets. This was observed by the reactor foreman, Valery Perevozchenko. He was observing from above just before the explosion. He felt the shock waves as the blocks (each weighing 350 kg) above fuel channels jumped up and down. He started down the stairs to the corridor that led to the control room.

The reactor reached 120 times full power, and the radioactive fuel disintegrated. Pressure from the steam broke the pressure tubes instead of going to the turbines. This led to an explosion. The first explosion occurred at 1:23:44 AM, followed quickly by a second more powerful explosion (2 or 3 seconds after the first). These explosions blew the 1,000-ton lid off the reactor, and a fireball lit up the night sky. The first explosion preceded the release of radiation. Air reached the reactor, and the oxygen in the air started a graphite fire. The metal of the fuel tubes had a chemical reaction with the water, producing hydrogen. The hydrogen exploded (second explosion). Some of the burning debris landed on the roof of unit number 3 and started a fire there. Dr. Richard Wilson of Harvard University stated that the second explosion was a small nuclear explosion, but most discount that theory. Dr. Wilson has examined the medical effects after the disaster.

After the second explosion, several employees went outside to examine the extent of the damage. One of them, Alexander Yuvchenko, stated that when he went out and looked towards the reactor hall, he saw a light. He described the light as a "very beautiful" laser-like beam of blue light. The beam was likely caused by the ionized air glow. The hot particles of nuclear fuel that were released included the isotopes caesium-137, iodine-131, and strontium-90.

The explosions started fires on the roofs of reactor number 3 and the turbine hall, which was adjacent to reactor number 4. Bitumen, which was flammable and against safety regulations, was used in the construction of the roofs of the reactor and turbine hall buildings.

The explosions killed two plant workers. Valery Khodemchuk, the main circulating pump operator for the night shift, was likely killed instantly. His body was never recovered, and he is entombed in the reactor debris.

A blackout occurred at the plant, leaving only battery-powered emergency lights operating, and the air was filled with dust and graphite chunks. Radiation (400 times more than the Hiroshima bomb) began gushing out. Walls and equipment at the plant collapsed, and fires started, including the fires on top of the neighboring reactor. The nuclear engineer in charge of the test insisted that reactor number 4 was still intact.

The Response

The fire department was called at 1:26:03 AM by Akimov after being ordered by Dyatlov. Akimov insisted that reactor number 4 was intact and ordered the emergency feedwater pumps to be turned on. Akimov sent Gennady Metlenko to the turbine hall to assist with the manual opening of the cooling system valves. Valery Perevozchenko came and reported that the reactor was destroyed, but Akimov still insisted it was intact.

The first firefighters arrived at the scene at 1:28 AM with no knowledge of the radiation release. They wore no protective clothing, and many of them would be among the 28 killed by acute radiation exposure. Later accounts from the firefighters who helped fight the fires described the fallout as "tasting like metal" and the feeling of pain like pins and needles on their faces. New teams of firefighters arrived at 1:45 AM. They also had no protective clothing or dosimeters, as they too were not informed of the radiation. One firefighter kicked a piece of graphite on the ground, while another picked up a piece and said, "hot."

The first firefighter on the scene was Lieutenant Volodymyr Pravyk. He coordinated the firefighting efforts until Telyatnikov arrived. He received a lethal dose of radiation and died on May 11, 1986, of acute radiation sickness.

One of the other firefighters who died a couple of weeks later was Vasily Ignatenko. He was a senior sergeant and was part of the first crew on the roof of reactor number 3, attempting to extinguish the fire there. He received a fatal dose of radiation and died on May 13, 1986, at Moscow Hospital 6.

At 2 AM, Dyatlov ordered Akimov to feed water to the reactor. Dyatlov and Gorbachenko, a radiation monitoring technician, went to survey the plant from the outside. Despite seeing the fuel and graphite scattered all around the ground, Dyatlov still believed the reactor was intact. Dyatlov reported his assumptions as fact to Bryukhavov and Fomin (higher-level managers). Later, at 5 AM, Dyatlov fell ill while in the bunker and went with Gorbachenko to the medical unit for treatment.

The local Soviet officials of the Pripyat department of the Ministry of Home Affairs convened an emergency meeting at 2:15 AM. At the meeting, they decided to block cars entering or leaving Pripyet. Police officers assisted with the roadblock. Like the earlier firefighters, they had no knowledge of the radiation release, wore no protective clothing, and had no dosimeters.

Viktor Bryukhanov, the plant's manager, arrived at the bunker under the administrative block at 2:30 AM. At the same time, Akimov reported that there had been a radiation accident, but that the reactor was intact and the fire was in the process of being extinguished. Akimov also stated that a second emergency water pump was being readied to cool the reactor. The radiation levels were seriously underestimated due to the limitations of the instruments. The reading was 3.6 Roentgen on one side of the control room, which was the maximum the instrument would read. At approximately 3 AM, Bryukhanov called Maryin, the deputy secretary for the nuclear power industry, and gave a report of the situation (according to Akimov's version).

At 3:30 AM, Akimov was contacted by the fire brigade commander, Telyatnikov. Telyatnikov wanted to know what was happening to his firefighters, who were exhibiting symptoms of radiation exposure. Akimov sent a dosimetrist.

Nikolai Fomin arrived at the control room at 4:30 AM. He ordered the continuous feeding of water into the reactor to cool the core. This was already in progress using emergency pump 2 from the deaerators.

On April 26, 1986, at approximately 5 AM, reactor number 3 was shut down. It was not restarted until April 21, 1987. Reactors 1 and 2 would be shut down the next morning and would be restarted a few months later (reactor number 1 on September 29, 1986, and reactor number 2 on November 9, 1986). The smaller fires had been put out by 6:35 AM and took 186 firefighters (37 fire brigades) that had been called in to fight them. The fire in the reactor core burned for two more weeks. The IAEA stated on May 10 that the reactor fire was out, while at the same time, Ukrainian authorities maintained that the fire was still burning, and firefighters were continuously working to put it out.

At approximately 5 AM, Dyatlov reported to Bryukhanov in the Civil Defense Bunker of the plant. He showed Bryukhanov the final printouts of the reactor state before the explosion and speculated on the cause. He did not report the destruction of the reactor. He was already feeling ill and was overcome by weakness while in the bunker. He was sent with an escort to the medical unit. Fomin replaced Dyatlov with Anatoly Sitnikov. After Dyatlov left the control room, Fomin ordered Sitnikov to survey the reactor from the roof of Unit 3. He returned at approximately 10 AM and reported to Fomin and Bryukhanov that reactor 4 had been destroyed, but they refused to believe him. Sitnikov received a fatal dose of radiation while performing the assignment.

At 6 AM, Akimov was replaced in the control room but stayed at the plant with Toptunov. They believed that the water flow had been blocked to the reactor. They went to the feedwater room and spent several hours turning valves. They received a radiation dose that would kill them a few days later.

On the afternoon of April 26, the Soviet Union mobilized troops to fight the fire. Some were dropped on the roof of the reactor to shovel debris off and spray water on the exposed reactor core in an attempt to keep it cool. They were then quickly picked up to minimize their exposure to radiation.

At 8 PM, a government committee was established to be led by Valery Legasov. They were surprised by bits of graphite on the ground when they arrived. A graphite fire was not suspected.

Within hours of the disaster, a secret message was sent from the Soviet Deputy Energy Minister Alexei Makukhin to the Soviet Communist Party that made several false statements concerning an explosion in the upper part of the reactor, the collapse of the walls and part of the roof. It further stated that the staff was taking measures to cool the reactor and there was no reason to evacuate Pripyat. It stated that 25 paramilitary fire personnel were hospitalized and made no mention of deaths. His message also stated that the fire was extinguished at 3:30 AM.

At 7 AM on April 27, 1986, General Pikalov approached the plant in a truck fitted with radiation detectors. He rammed the gate and stopped at the plant to measure the radiation. He was able to establish that the graphite from the reactor was burning and releasing a large amount of radiation and heat. The warning was sent to Moscow shortly afterward.

After General Pikalov made the radiation readings, the government committee discussed evacuating Pripyat. All supported evacuation, except Professor A.L. Ilyin, chairman of the Soviet Council for Radiation Protection. He thought the radiation situation would improve.

On April 27, 1986, at approximately 10 AM, Soviet helicopters began dumping sand, clay, boron carbide (a neutron absorber), lead, and dolomite into the still-burning core of reactor number 4. This was an attempt to slow down the radioactive emissions. Almost none of the neutron absorbers reached the core. This step was taken after water did not extinguish but rather fanned the flames, as the extreme heat separated the water into hydrogen and oxygen gas (both flammable).

Evacuations Begin

It was a day later that action happened in Pripyat. The only signs of anything out of the ordinary were the sight of trucks cleaning the streets with foam. Within a few hours of the accident, dozens of people in Pripyat fell ill. They later reported severe headaches and a metallic taste in their mouths. They also reported uncontrollable coughing and vomiting.

On April 27, 1986, the residents of the city of Pripyat (population approximately 50,000) were evacuated (36 hours after the explosion), as well as residents of nearby areas (10 km around the plant). The buses began to arrive in Pripyat from Kiev at midnight. They then waited for the order to evacuate the city. The radiation levels dropped slightly by noon, giving hope that no evacuation would be necessary. They then began to rise again, and the evacuation order was given at 2 PM. The citizens of Pripyat were told that it was temporary (3 days) and they should bring only vital documents and belongings. In addition, dosimeters were confiscated. They were given two hours to gather their belongings. There were 1,200 buses, and it took three and a half hours to evacuate the city. Soon after their evacuation, an exclusion zone was set up around Chernobyl that prevented their return. Pripyat was eventually replaced by Slavutych.

There was a meeting of the CPSU Politburo on April 28, 1986, to discuss the accident and the needed response. In this meeting, they first discussed what was known and what was being done. Sixty sacks of sand and boron had been dropped out of the needed 1,800. The head of the KGB, Viktor Chebrikov, stated that the population was calm and that only a few people knew about the accident. Gorbachev wanted to issue a statement without delay that there was an explosion and that they were taking measures to eliminate the consequences. He also then stated that work on decontamination needed to continue and that necessary measures should be taken to prevent looters. Gorbachev wanted to ensure that the Soviet public was informed about the accident.

Pripyat was quietly evacuated before the outside world found out about the accident. Air monitors in Sweden detected a large amount of radiation in the atmosphere on April 28, 1986. Operators of Forsmark Nuclear Power Plant in Stockholm registered abnormally high radiation levels near their plant, which was 620 miles from the Chernobyl NPP. It was originally picked up when a routine check showed that the soles of shoes worn by a radiological safety engineer were radioactive. Swedish officials traced this release back to the Soviet Union after workers at Forsmark reported the issue to the Swedish Radiation Safety Authority. Soviet officials made no statement until Swedish leaders demanded an explanation. Soviet officials at the Kremlin

admitted on April 28, 1986, that there had been an accident but lied and stated that the situation was under control.

At the same time that rumors started being circulated in Sweden (Forsmark) about radioactivity leaking from one of their blocks, news arrived that radioactivity had been detected in Finland. After an investigation, it was determined at approximately 3:30 PM that the radiation did not come from Forsmark.

On April 28, 1986, a broadcast was made at 8 PM on Radio Moscow of a statement issued by Tass (the Russian state-owned news agency). It stated that there had been an accident at the Chernobyl nuclear power station. The statement mentioned casualties without specifying a number. The Tass report further advised that "Measures are being taken to eliminate the consequences of the accident. Aid is being given to those affected. A government commission has been set up." The report was vague and provided no real information, reflecting the minimum that Gorbachev had stated in the Politburo meeting. Their statement was followed by a broadcast about the Three Mile Island accident of 1979 and incidents in other Western countries. Approximately 30 minutes later, Western European news agencies started reporting an "incident in a Ukrainian nuclear reactor."

There were press reports on April 29, 1986, on the main Russian evening news program, Vyrema. It was the sixth item on the news, so they buried the story. The story stated that two people died during the accident and a portion of the reactor building was destroyed. It also mentioned that the residents of Pripyat and other nearby towns were evacuated.

The first glimpse into the destruction by the Western world was provided by a United States reconnaissance satellite on April 29, 1986. Analysts in Washington DC were shocked to see the roof blown off the reactor and a glowing mass that was still smoking. The first Soviet photos of the accident were doctored to remove the smoke before being printed in the newspapers.

On April 30, 1986, Tass carried another government statement that denied Western reports about mass casualties. The statement reiterated that two people were killed and that 197 had been hospitalized. It also stated that radiation levels were decreasing. Some sources state that 237 workers were hospitalized, not 197 as Tass reported.

Soviet bureaucrats immediately removed their children from Kiev after the accident while stating to the citizens that everything was "normal." In a 2006 interview for a documentary, Mikhail Gorbachev stated how important it was to them at the time to not cause panic.

The material that was thrown onto the top of the reactor did not extinguish the fire but generated a rise in temperature. The engineers became aware of a new danger from the reactor: there was a concern that the reactor core could melt into the cement and end up in the water reservoir underneath it. The concern was the steam explosion that would follow, which would be more powerful than the first explosion.

There were two floors of bubbler pools beneath the reactor that served as a reservoir for water as part of the emergency cooling pumps. These pools and the basement flooded during the firefighting efforts. The graphite and other material that was more than 1200 degrees Celsius were feared to burn through the reactor floor into the pool of water. This could have caused a steam explosion that could release more radioactive material. It became necessary to drain the pool of water. Three engineers volunteered who could open the necessary valves: Alexei Ananenko, Valeri Bezpalov, and Boris Baranov. All three survived.

Liquid nitrogen was pumped under the reactor on May 4, 1986, after the fire in the core had burned itself out. This was done to cool the reactor and was another step to prevent a steam explosion. However, the idea was scrapped after it was started. Instead, it was decided to have miners excavate a tunnel below the reactor to install a cooling system. The tunnel was filled with concrete after the fuel came to rest.

Contaminated villages were bulldozed, and contaminated pets and livestock were shot. A large amount of contaminated topsoil was buried. On May 5, 1986, construction began on an embankment on the Pripyat River in an attempt to prevent contamination of the river from radioactive fallout.

Also on May 5, 1986, an IAEA delegation arrived in Moscow. The delegation was headed by the director-general of the IAEA, Hans Blix. The radioactive cloud that was released spread as dust and debris nearby, and some of it was carried by the wind and spread throughout the Soviet Union and Europe. There was a 1.5 square mile area of pine forest directly downwind of the reactor that turned reddish-brown and died due to radiation. It was named the "Red Forest."

On May 4, 1986, the first film footage was shown on Vremya. It was shot from a helicopter, and the commentator claimed that the film disproved Western claims of mass destruction. Pravda carried the first extensive report of the accident on May 6, 1986. The next day, Tass reported that many Kiev residents were trying to leave the city. Tass also reported that extra trains and flights were scheduled. The Soviet media also stopped reporting that everything was under control.

Soviet officials closed schools in Kiev and Gomel on May 6, 1986. Residents of Kiev (via Kiev radio) were also advised to stay inside as much as possible and not to eat leafy vegetables. Radioactive emissions dropped sharply since the fire in the core had burned itself out. On May 8, 1986, workers finished draining the radioactive water from the basement under the reactor core. The plant released a large number of radioactive substances for 10 days, including iodine-131, caesium-137, plutonium, and strontium-90, the four most harmful radionuclides. Iodine-137 becomes concentrated in the thyroid and milk glands, leading to an increase in the rate of thyroid cancer. Caesium tends to accumulate in the heart and other vital organs. Strontium accumulates in the bones and can be a risk to bone marrow.

On May 10, 1986, Aleksandr Akimov died from radiation he received during his attempts to restart the feed water flow into the reactor core that was no longer there.

On May 10, 1986, Vladimir Gubarev wrote a lengthy letter to the Communist Party of the Soviet Union. Gubarev was the Pravda Science Editor and had just returned from a trip to Chernobyl. His purpose was to share some of his observations with party officials. He had several points:

1) There were no emergency evacuation measures for the city of Pripyet, so the people did not know what to do. The instructions and orders that had been in existence for 25 years about evacuation of the local population was to be taken by the local leadership. He stated that nobody was willing to make the decision to evacuate, noting that the Swedes evacuated people from the area of their station before finding out that the release was not theirs.
2) Soldiers and pilots did not have individual protection. Officers showed off their bravery (or stupidity) by appearing next to the reactor wearing normal uniforms.
3) The drivers that evacuated Pripyat did not have any protection. Also, the workers that built levies along the Pripyat River did not have proper protection.
4) The civil defense system was a complete disaster in itself without any working dosimeters.

5) The firefighting units did their job well. They prevented the accident from spreading. They did not have appropriate protection.
6) The machine room roof was made from flammable materials.
7) Attitude towards nuclear power stations lower within the Ministry of Energy for several reasons, to include personnel cuts, reduction of equipment supplied, cutting time of scheduled repairs, a lot of paperwork, and treating nuclear power stations like coal power stations.
8) The local officials were extremely inefficient when attempting to help victims of the disaster, often waiting for supply orders from Moscow.
9) People in Kiev seemed panicky due mainly to lack of information about radiation levels. Foreign propaganda had a large influence due to the lack of reassurance from Soviet officials. This panic was not helped when the people found out that the families of the leadership were leaving the city. The Communist party waited for instructions from Moscow, instead of giving any information to the public.
   There was an exception, where the Secretary of the Kiev regional party committee, Comrade Revenko kept the secretaries of regional committees informed, and the ordinary communists. As a result, that region did not have the same level of panic. It helped that Revenko had visited Chernobyl regularly.
10) We have to explain to the people how to safely live in an area that has been contaminated with radioactive material.

On May 14, 1986, Mikhail Gorbachev spoke publicly about the accident for the first time on Vremya. He insisted that reliable data was promptly provided to the Soviet people and shared internationally. He also denied any cover-up and pledged to make all accident details available to the world. Gorbachev expressed his willingness to cooperate with the IAEA and put forward four proposals. The first proposal aimed at establishing an international regime for the safe development of nuclear energy, emphasizing close cooperation among all countries utilizing nuclear energy. He also called for a special international conference under the IAEA in Vienna and advocated for an expanded role and scope for the IAEA. Additionally, Gorbachev proposed the safe development of peaceful nuclear activities under the United Nations. On Soviet state television, he stated that "the worst is behind us" and ordered hundreds of thousands of firefighters, military reservists, and miners to aid in the cleanup efforts.

On June 15, 1986, Pravda reported that most of the management team, including Chernobyl Director Victor Bryukanov and his deputies, including Nikolai Fomin (senior engineer), were dismissed. Their dismissal was attributed to "irresponsibility and lack of control."

On July 3, 1986, a Politburo meeting took place, and Central Committee member Anatoly Chernyaev took notes of the session. During the meeting, Chairman Gorbachev expressed disappointment with the unpreparedness of civil defense and medical services, as well as the inadequate supply of dosimeters. He remarked that everyone "panicked" and criticized the absence of an alert system and the failure to track the path of the radiation cloud. Gorbachev questioned why the reactor design was still in use and expressed frustration with the inefficiency of the system, saying, "Where centralization is needed, we don't have it; however, where a simple nail needs to be hammered in, thousands of agencies get involved." He also highlighted the significant political damage caused by the accident, as it led to doubts about the Soviet energy program. The Minister of Energy and Electrification, Mayorets, admitted being falsely informed at the beginning of the fire that it had been extinguished. He also mentioned the 1975 accident at the Leningrad NPP and the failure to learn from it.

On July 20, 1986, a summary report by the Soviet government attributed the disaster to human error. The full report was released a month later, on August 20, 1986, to the IAEA. It concluded that a series of carelessness, safety code violations, and mismanagement had led to the accident. The report held the station personnel responsible for the accident but attributed the magnitude of the disaster to the reactor's design.

On August 26, 1986, the Estonian press reported strikes and demonstrations by forcibly conscripted military reservists in Estonia who were involved in the Chernobyl cleanup. In November 1986, they reported that 12 people had been executed.

In 1989, the second phase of the resettlement process began, requiring 100,000 people to leave contaminated areas in Belarus, Russia, and Ukraine. On October 26, 1989, Tass reported that evacuations would continue in 1990, with 100,000 people being evacuated from contaminated areas in Belarus.

In April 1991, Soviet authorities announced that 200,000 people had been evacuated. They further stated that 112,000 would be evacuated in 1991 and an additional 12,000 in 1992.

Sarcophagus Constructed

The IAEA reported that Soviet authorities had begun encapsulating the reactor. Workers began pouring concrete under the reactor on May 9, 1986. A foundation of lead had accidentally been created from the material thrown on the burning reactor, which melted and leaked under the reactor, solidifying as the temperature decreased. This was later encased in a concrete and metal structure to contain the core radiation. The structure became known as the sarcophagus.

In the months following the explosion, a lot of attention was focused on removing debris from the roof of reactor number 4 so that the sarcophagus could be safely constructed. There was approximately 100 tons of debris on the roof that needed to be removed. Initially, it was planned to use robots to clear the debris. However, most of these robots failed due to the radiation's effect on their batteries and electronics, as well as the challenging terrain. Valery Legasov noted in 1987 that the electronics ceased to function due to the radiation, rendering the robots useless. The solution was to have members of the military, known as "bio-robots," wearing heavy protective gear to shovel the material off the roof. They could only spend a maximum of 90 seconds working on the roof due to the high radiation from the graphite. Approximately 5,000 men performed this task, each receiving an average dosage of 25 rem of radiation.

The sarcophagus was hastily constructed over a period of 206 days. The design of the sarcophagus began on May 20, 1986. It was constructed to prevent the spread of contamination caused by wind, birds, or rainwater, which could seep into the water table. In January 2017, a former worker named Yaroslav Melnik told the BBC, "We worked in three shifts, but only for five to seven minutes at a time because of the danger. After finishing, we would throw our clothes in the garbage." The construction work included building walls around the perimeter, laying concrete, and erecting a shielding wall to protect the workers of reactor number 3.

The sarcophagus was completed on December 14, 1986. Its purpose was to prevent the further release of radioactive particles into the atmosphere. It was also intended to isolate the exposed core from the weather and provide safety for the continued operation of the other reactors. It was built to protect the environment from radiation for at least 20 to 30 years. This was announced by Soviet scientists on December 22, 1986. The power plant roof collapsed on February 13, 2013, due to heavy snowfall. However, the collapse did not affect the sarcophagus.

Deep within the basement of reactor number 4 lies the Chernobyl Elephant's Foot, which is a mass of melted concrete, sand, and radioactive nuclear fuel. It was named for its appearance, described as resembling an elephant's leg and foot. In the 1980s, it emitted an estimated 10,000 roentgens of radiation per hour. This amount of radiation is sufficient to kill a person standing 3 feet away in under 2 minutes. By 2001, this rate had decreased to approximately 800 roentgens per hour.

In August 1986, the International Atomic Energy Agency (IAEA) hosted a conference where scientists attributed the accident to human error, subpar safety culture, and design flaws in the reactor.

On October 11, 1991, a fire broke out in the turbine hall of reactor number 2. It originated in turbine number 4 while it was shut down for repairs. The fire was an electrical one caused by a faulty switch. The switch resulted in a surge of current to the turbine, igniting the insulation material on the wiring. This led to the release of hydrogen (used as a turbine coolant), creating conditions for a fire to start on the roof. One of the trusses supporting the roof collapsed. Reactor number 2 was permanently shut down after being declared irreparably damaged.

In July 1992, the Ukrainian government held an international competition, known as the Shelter-2 competition, for proposals to replace the sarcophagus over reactor number 4. This decision came after the Ukrainian government reported in March that cracks had appeared in the sarcophagus. The competition concluded on June 18, 1993, with only one proposal suggesting a sliding arch approach. Following a subsequent study, the sliding arch approach was selected due to the significantly reduced risk of construction workers receiving a harmful dose of radiation. The replacement structure became known as the New Safe Confinement.

On April 25, 1996, a French government minister admitted to being misled about the radioactive cloud and the impact of the disaster. State television weather forecasters even went so far as to announce to viewers that the radioactive cloud had stopped at the border of France.

The contract for the New Safe Confinement was signed on September 17, 2007. The French consortium Novarka was responsible for constructing the structure, which was a 15 by 257-meter arched edifice. Construction of the larger and more secure sarcophagus began in 2010. Weighing 35,000 tons, it was built on tracks to be slid over the reactor and existing sarcophagus. The two halves of the New Safe Confinement were joined on July 24, 2015, and it was slid into position in November 2016. It was designed to last for 100 years.

Reactor 3 was shut down on December 15, 2000, marking the closure of the last operational reactor at the plant. Reactor 1 had been shut down in 1996, and reactor 2 had been shut down in 1991.

The Chernobyl disaster exposed the Soviet Union's lack of transparency, not only to its own people but also to the international community. The cleanup efforts incurred billions in costs. In April 2006, Mikhail Gorbachev wrote that the Chernobyl disaster "perhaps more than my launch of Perestroika, was the real cause of the collapse of the Soviet Union." At the time of the accident, Gorbachev was criticized by the Western media for a delay of 18 days before publicly addressing the disaster.

Liquidators

From April to October 1986, the Soviet government mobilized several hundred thousand people from all around the Soviet Union, many of whom were military reservists. They were either recruited or forced to participate in the cleanup of the accident and became known as "liquidators." The Soviet government compelled many soldiers to assist in the cleanup, often under deplorable conditions and without sufficient protective clothing. They were also not informed of the dangers involved and likely exceeded safe radiation limits.

Urban liquidators were responsible for washing buildings and roads using a fluid known as "Barda," which was a sticky polymerizing substance designed to trap radioactive dust. The number of liquidators involved in the first year was approximately 650,000, mostly male. It is estimated that the total number of liquidators exceeded 1 million. Many of those who worked as liquidators fell ill, and between 8,000 and 10,000 died from radiation exposure during the cleanup in the first years after the accident. Additional deaths occurred in subsequent years due to cancers or other health issues caused by radiation. While many liquidators were praised as heroes, others struggled for years to have their participation recognized. A Soviet badge was awarded to the liquidators.

In 1991, all further work in the zone was to be carried out on a professional basis. All those who worked in the zone until 1990 were granted the status of liquidator, regardless of their assigned tasks. This status entitled them to social benefits.

The health effects on the liquidators differed significantly from those on the average Soviet citizen. It is impossible to determine the exact dosage they received. In 1991, Dr. Leonid Ilyin provided some unofficial figures, stating that approximately 100,000 civilians received an average dosage of 21 rem, while 200,000 received an average of 11 rem in the second year.

The International Atomic Energy Agency (IAEA) concluded that the death rate among liquidators was not higher than normal. However, the IAEA failed to address the high incidence of diseases and showed a lack of appreciation for the work done by the liquidators. Additionally, the IAEA denied the significant increase of leukemia among liquidators that had been found. A study on a group of liquidators indicated that cases of leukemia peaked five years after their work. Since the expected time between receiving a high dose of radiation and developing leukemia is five years, the relationship should be evident.

In June 2001, an international scientific conference titled "Health Effects of the Chernobyl Accident: Results of 15-Year Follow-Up Studies" was held in Kiev. One of the findings was that the health status of liquidators had significantly deteriorated since the accident. They had a higher rate of general somatic diseases, and morbidity increased more than 17 times between 1991 and 2000.

According to the 2006 IPPNW report, between 50,000 and 100,000 liquidators had died by 2006, and between 540,000 and 900,000 liquidators had become invalids. The effects of congenital defects in the children of liquidators and residents of contaminated areas on future generations cannot be predicted at this time.

Deaths and Health Effects

The long-term health effects and deaths resulting from the accident are disputed. There were two plant workers killed in the initial explosions, and 28 individuals died from acute radiation exposure during the initial firefighting and cleanup. Before discussing the health effects, it is important to mention a few points about radioactivity.

Radioactivity occurs when an atomic nucleus decays and breaks down into particles and energy. The types of particles involved include alpha particles (helium nuclei), beta particles (electrons), neutrons, and gamma rays. The strength of a radiation source is measured in curies (Ci), which are conventional units. One curie is equivalent to 37 billion nuclear decays per second. The time it takes for half of a quantity of a radioactive isotope to decay is known as its half-life.

Radiation is measured in roentgen (R) or rems when discussing the dosage received by biological tissue. One rem is the amount of radiation that transfers 6 X 107 million electron volts (MeV) of energy to one gram of biological tissue. For our purposes, we will assume that one roentgen is equal to one rem.

To understand the dosage, let's consider the example of 750 R. This high dosage usually results in certain death within a few weeks. A lower dosage of 450 R provides a 50 percent chance of recovery. A dosage of 200 R or less almost guarantees recovery. Dosages between 25 R and 150 R may only cause a temporary decrease in red blood cells, and this effect is not observed for dosages less than 25 R.

The radiation levels immediately after the accident should be noted based on Dr. Wilson's interview. Just downwind of the plant, the radiation levels were several hundred rems per hour, which is lethal within an hour or less. The radiation levels in Pripyet were initially low but reached 1 rem per hour on Kurchatov Street, the area closest to the plant. Exposure to this level of radiation for 2 weeks is lethal.

The ionizing radiation levels in the most heavily affected areas of the reactor building were estimated to be 5.6 roentgens per second (over 20,000 roentgens per hour). A dose of 500 roentgens over five hours is considered lethal, and some workers received a fatal dose within a minute. Most of the available dosimeters were low-level (3.6 R/h) and provided inaccurate readings.

The slow evacuation of the town of Pripyet is a point where Dr. Wilson approximated the dosage received. He stated that there was no evacuation for 36 hours, and then only the town of Pripyet was evacuated. The remaining areas within a 30 km radius were evacuated a few days later. Many of these people received 45 R. Dr. Wilson also described the likely disappearance rate of radioactive particles. Iodine would have dissipated within 3 weeks, while Caesium-137, with a 10-year half-life when deposited as fallout, has a physical half-life of 30 years. The International Committee on Radiological Protection recommends evacuation if a total dose of 50 rems is expected.

The most severe cases of acute radiation syndrome were treated with the assistance of Robert Peter Gale from Los Angeles. He attempted bone marrow transplant procedures, which were unsuccessful. The patients he treated included station operators and firefighters, many of whom suffered beta burns from Np-239. His involvement was depicted in the 1991 movie "Chernobyl: The Final Warning."

On April 29, 1986, Polish authorities decided to distribute iodine tablets to infants and children in certain areas in the northeast part of the country as an attempt to protect them from thyroid cancer.

On May 23, 1986, a Soviet government committee ordered the distribution of iodine preparations. Radioactive iodine is active for ten days and would have already accumulated in the thyroid glands.

In 1988, it was revealed that 16,500 police officers were deployed in the area. At that time (1988), many of those officers experienced health effects, including 57 with chronic radiation illness, 1,500 suffering from chronic respiratory problems, and 4,000 suffering from other ailments.

On May 21, 1991, the IAEA/IAC released a study titled "Assessment of Radiological Consequences and Evaluation of Measures for the Chernobyl Accident." The study made several claims. The first claim was that there were no health disorders directly attributable to radiation exposure and no increase in the incidence of leukemia and cancers. The study also claimed that there were significant non-radiation-related health disorders in contaminated population centers and control populations. It further claimed that there were substantial negative psychological consequences in terms of stress and anxiety related to relocation and

uncertainty. The study also stated that the relocation and protective measures were reasonable and the procedures for measuring doses were sound.

There were several criticisms of the IAEA report of May 1991. It excluded the estimated 600,000 liquidators from the investigation. It also did not include the Exclusion Zone or its evacuees. It excluded hot spots. There were ambiguous reasons why the populations were chosen for the study and how the control groups were obtained, possibly skewing the results. Additionally, the exposures were grossly underestimated, particularly the lifetime dose, with the external dose at one third to one fourth and the internal dose at one tenth of the actual exposure.

The IAEA attempted to attribute the increase in diseases to psychological stress. However, the only cause of an increase in thyroid cancer and leukemia would be radiation. The IAEA's projections of future cancer deaths were very low, considering the dose that the liquidators and area residents received. Calculations were made using the dose-effect numbers from the International Commission on Radiation Protection (ICRP) and projected 50,000 to 70,000 deaths due to radiation in the first two years after the accident. American radiation expert John Gofman also made calculations, estimating 317,000 to 475,000 deaths worldwide.

The environmental organization Friends of the Earth claimed that the IAEA scientists were incompetent. This was based on the fact that IAEA scientists drew concrete conclusions from what they admitted was insufficient data. Greenpeace stated that the only reason for the study was to "produce a thirty-second sound bite that is pleasing to the ear of the Soviet authorities." It was carefully constructed to avoid implicating radiation in the disaster.

Sources such as Nuclear Monitor have highly criticized the IAEA study as "rubbish." The IAEA was accused of deliberately downplaying the true extent of the catastrophe and some statements were challenged as demonstrably false. It was also suggested by experts that the IAEA may have exerted too much influence on the study.

A well-known expert, Dr. Rosalie Bertell, made many comments on the IAEA press release. One of the comments was on the statement "an estimated 2,200 radiation-caused deaths can be expected during their lifetime." This referred to the 200,000 emergency and recovery workers exposed. Dr. Bertell commented that the statement assumed that only death is considered detrimental, and all other severe and debilitating morbidity is eliminated from the statistics. As an example, the International Commission on Radiological Protection (ICRP) has released

documents that have been accepted without question, prescribing that the only health effects to note are deaths from cancer. They were not concerned with non-fatal cancers.

Dr. Angelica Claussen of the International Physicians for the Prevention of Nuclear War (IPPNW) commented on the IAEA studies. Studies conducted for the International Chernobyl Project of the IAEA were carried out between January 1990 and February 1991. In 1990, the rate of new cases of thyroid cancer in children in Belarus was 30 times higher than the 10-year average. These numbers directly contradicted the IAEA report, which stated that the official data did not indicate a marked increase in leukemia or cancers. The BBC conducted independent research that indicated the IAEA Chernobyl Project perpetrated a deliberate deception on the public.

On December 12, 1991, two former Bulgarian ministers were sentenced to prison. They were found guilty of covering up the dangers of the Chernobyl disaster from the Bulgarian population.

In February 1994, the Massachusetts Institute of Technology (MIT) released a report on radiation emissions at Chernobyl. The report stated that emissions were five times higher than the official IAEA estimates of 50 million curies. The MIT study claimed that 185-250 million curies were released.

In March 1995, the WHO claimed in a report published in a British journal that there were 100 times more thyroid cancers in Gomel, Belarus. The government of Ukraine stated in April 1995 that 125,000 people died from the effects of Chernobyl radiation, 432,000 were still being treated, and 3.66 million were affected by the disaster. In July of the same year, the WHO stated in a resolution adopted at a conference in Kiev that mental disorders were being diagnosed among the Chernobyl-affected population. That same year, the WHO presented findings at a conference in Geneva, indicating that radiation could be increasing the incidence of stroke, heart attacks, and liver disease. The findings also indicated damage to the brains of babies in the womb.

In April 1996, it was reported that genetic mutations occurred at twice the rate in children of families exposed to the radioactive fallout compared to families not exposed.

The Soviet government did not conduct any studies following the accident to assess the effects on the workers, liquidators, or the population as a whole.

It was revealed on November 11, 1996, that cases of thyroid cancer among children had increased by 200 percent compared to the 1980s. The WHO estimated that approximately 1 million people were receiving medical treatment out of the 4 million affected by the disaster.

On November 26, 1998, a scientific seminar on "Thyroid Diseases and Exposure to Ionizing Radiation: Lessons Learned Following the Chernobyl Accident" was held in Luxembourg. It was organized by the European Commission. One of the major health issues discussed was the significant increase in thyroid cancers, especially among children. The seminar aimed to review the existing knowledge on radiation-induced thyroid diseases, particularly related to the Chernobyl accident.

In March 2000, Vladislav Ostapenko, the head of the Belarus Radiation Medicine Institute, discussed deformations of reproductive systems. He stated that girls in the affected areas had five times the normal rate of deformations in their reproductive systems, while boys had three times the normal rate. Ostapenko concluded that genetic changes were evident in children exposed to radiation.

In April 2001, an international conference titled "Fifteen Years After the Chernobyl Accident – Lessons Learned" took place in Kiev. During the conference, UN organizations, the IAEA, and experts reached a consensus on the health effects of the disaster. They acknowledged a direct link between the accident and thyroid cancer among children and discussed other observed effects, although limited resources hampered further investigations.

In November 2004, scientific evidence emerged suggesting that fallout from Chernobyl may have increased cancer rates in Western Europe. Swedish researchers found a statistically significant correlation between the level of fallout and the observed rise in cancer cases.

A United Nations report in 2005 estimated that fewer than 50 people died in the months following the accident. The report also stated that up to 9,000 people could eventually die from cancer resulting from the accident. By 2005, the Union of Concerned Scientists estimated that 6,000 thyroid cancers and 15 thyroid cancer deaths could be attributed to Chernobyl.

On December 16, 2005, the Central Service for Protection Against Radioactive Rays (SCPRI) in France became aware of contamination in Corsica and southeastern France but kept the information secret. The study was commissioned by a magistrate investigating allegations that an atomic cloud from Chernobyl caused a surge in thyroid cancer cases in parts of France.

On April 6, 2006, The New Scientist magazine quoted two independent scientists from the United Kingdom who accused the IAEA and the WHO of downplaying the impact of the Chernobyl disaster. Ian Fairlie and David Sumner stated that the death toll from cancers would reach between 30,000 and 60,000, up to 15 times more than the official estimates. They accused the IAEA/WHO report, released on September 5, 2005, of disregarding its own prediction of an additional 5,000 cancer deaths in the less contaminated parts of Ukraine, Belarus, and Russia. They also accused them of failing to account for thousands more deaths in other countries where over half of the Chernobyl fallout ended up. Zhanat Carr, a radiation scientist with the WHO, admitted that the deaths were omitted because the WHO report was a "political communication tool." Other experts supported the accusations made by Fairlie and Sumner.

On the same day (April 6th), a report titled "Health Effects of Chernobyl – 20 Years After the Reactor Disaster" was released by IPPNW in Germany and the German Society for Radiation Protection. The report also highlighted the misrepresentation by the IAEA, which claimed that fewer than 50 people died as a result of the accident. It pointed out numerous inconsistencies in the IAEA figures. For example, the IAEA claimed that future deaths due to cancer and leukemia in the most heavily exposed groups would number 4,000 at most. However, the study referenced by the WHO in their report indicated an additional 10,000 to 25,000 deaths from cancer and leukemia. Dr. Pflugbeil from the German Society for Radiation Protection made this observation.

On April 18, 2006, a Greenpeace report stated that the full toll from the Chernobyl disaster could exceed a quarter of a million cancer cases, nearly 100,000 of which would be fatal. The report directly challenged the UN/IAEA Chernobyl Forum report, which predicted 4,000 cancer deaths. The new data from Belarusian cancer statistics projected 270,000 cancer cases, with 93,000 of them fatal due to the disaster. The report concluded that 60,000 people had died in Russia, with an estimated additional 140,000 deaths in Ukraine and Belarus. The health impacts indicated damage to the immune and endocrine systems, accelerated aging, cardiovascular and blood diseases, psychological illnesses, chromosomal aberrations, and fetal deformations.

Two decades after the accident at Chernobyl, the Chernobyl Forum Report stated that first responders and cleanup workers had been exposed to the highest levels of radiation. At the time, these personnel still had the highest rates of depression and PTSD.

On April 23, 2007, a study was released on birds around Chernobyl. The study suggested that nuclear fallout, rather than the impact of relocation, stress, and deteriorating living conditions as suggested by the IAEA, may be responsible for human birth defects in the area. The study compared 7,700 barn swallows from Chernobyl with birds from elsewhere and was conducted by Timothy Mousseau from the University of South Carolina at Columbia. It found that Chernobyl's swallows were more likely to have tumors, misshapen toes, and feather deformities compared to swallows from uncontaminated areas of Europe. Mousseau stated, "We don't fully understand the consequences of low doses of radiation" and further emphasized the need to be more concerned about the human population.

In June 2007, a report on the story of a New York-based medical specialist was published. The report stated that while the impact was often seen as a problem in Belarus, Ukraine, and Russia, the medical effects had spread worldwide. According to the report in Courier-Life Publications, "There are between 150 and 200 thousand people in the NY metropolitan area who come from the affected region, and the cancer rates are increasing."

Also in June 2007, a study from Linkoping University in Sweden, conducted in 2004, sparked much debate about the increased cancer rates in northern Sweden following the Chernobyl accident. The study observed a significant increase in cancer rates in northern Sweden, where the fallout of caesium-137 was most pronounced.

In August 2007, a study of Swedish children was conducted by Douglas Almond and Lena Edlund from Columbia University, along with their Stockholm University colleague, Martin Palme. The study examined 560,000 Swedish children born between 1983 and 1988. It found that children born in the months following the disaster suffered mental impairment from the radioactive fallout. Academic performance was generally weaker in children who were still in utero at the time of maternal exposure to radioactive fallout. This effect was most pronounced for fetuses between 8 and 25 weeks post-conception, which coincides with the peak period of brain development.

In October 2008, a study from Case Western Reserve University in Cleveland, Ohio, tracked the Chernobyl fallout. The study revealed that there was significantly more plutonium found in Swedish soil than in Poland at the same depth. Soil samples were taken in both countries to measure the presence and location of caesium-137, plutonium (239 and 240), and lead-210. Radionuclides can occur naturally or as fallout from nuclear testing. A spike of plutonium (239, 240) corresponding to the depth coinciding with the Chernobyl disaster was found in Sweden's

soil, but not in Poland's. Research showed that it rained in Sweden while the radioactive cloud was over the country, resulting in more contamination entering the soil.

In 2011, the United States National Institutes of Health conducted a study and concluded that thyroid cancers were likely the result of exposure to iodine-131 from Chernobyl fallout.

Evidence of developmental errors in the nervous systems of people exposed to radiation is widespread. These effects include reduced head size and brain damage. Low-level ionizing radiation can cause changes in both the central and autonomic nervous systems, as well as radiogenic encephalopathy. Studies have revealed changes in brain structure and cognitive disorders.

The Russian filmmaker Vladimir Chevchenko, who documented the early response to the disaster, died from radiation sickness in March 1987.

The Chernobyl Exclusion Zone

The explosion and radiation release left behind a significant amount of contaminated land, approximately 39,000 square miles. The regions worst affected were Belarus, Ukraine, and Russia, with most radioactive particles being released within 10 days of the explosion. Reports from both Soviet and Western scientists indicated that Belarus received approximately 60 percent of the contamination. A 2006 TORCH report stated that Ukraine, Belarus, and Russia were collectively contaminated by half of the particles. Sweden and Finland were the next worst affected areas outside the Soviet Union.

The Soviet authorities established an Exclusion Zone, initially with a radius of 10 kilometers in all directions (36 hours after the accident), which was later expanded to 30 kilometers. Eventually, it was enlarged to a 770-mile-wide Exclusion Zone. This area is officially referred to as the "zone of alienation" and is considered unsafe for human habitation. Additionally, it cannot be used for logging or agriculture due to the contamination of the soil and plants.

Looting has been an ongoing issue in the Exclusion Zone since the accident. To prevent theft, valuable items such as cars and electrical appliances were often broken or crushed after the accident. Many former residents of the region believe that some of their belongings were stolen. A former liquidator reported being "too busy and too scared to do it." In the mid-1990s, it was common for buyers to check the radiation levels of household goods for sale in the markets.

One of the individuals responsible for apprehending looters after the accident was Sergey Chernenky. Many looters aimed to sell contaminated goods in the markets of Kiev to make money. Chernenky recalled an incident where two looters attempted to steal a car from the Exclusion Zone. They drove a short distance before succumbing to radiation exposure. The contaminated car showed a reading of 6,000 roentgens.

In September 1988, the Soviet authorities decided to transform the 30 km zone into a national park, banning all human activity, including farming, within the zone.

In the early 1990s, elderly individuals began to reoccupy their houses in the exclusion zone, despite the ban on permanent residency within 15 km of the power plant site. Approximately 1,500 people resettled, with two-thirds being women. Another 50 individuals took up residence in Chernobyl itself, and the authorities tolerated this.

In September 2005, Ukrainian authorities discovered radioactive nuclear fuel believed to have been stolen from Chernobyl in 1995. During a routine search of the perimeter, they found a plastic bag containing 14 pieces of fuel. It had been abandoned there after the 1995 theft, which prompted the implementation of additional security measures to detect radiation.

On October 31, 2008, four individuals from the Kyiv region of Ukraine were found guilty of violating radiation safety requirements. In reality, they were involved in looting and attempted to remove 15 tons of contaminated scrap metal from the Exclusion Zone. The radiation levels on the metal were hundreds of times higher than the permissible limit, and the individuals were subsequently imprisoned.

Around the same time, two individuals from the Ivankiv District were arrested for attempting to remove metal from the Exclusion Zone without proper documentation.

In August 2005, radiation levels in the immediate area surrounding the Chernobyl Nuclear Power Plant had significantly decreased. Ukrainian authorities consequently reopened some parts of the evacuation zone for partial resettlement, although some residents had already returned illegally. These returning residents were known as "samosely." However, they lost welfare benefits that they were entitled to, as the Ukrainian government considered the residual radiation to pose less risk to their lives than continued separation from their homes.

In February 2011, Ukraine's Emergency Ministry began issuing licenses for tourist trips into the Exclusion Zone. However, on June 20, 2011, the Exclusion Zone was once again closed to tourists due to the suspension of tourist trips. The Prosecutor General's Office conducted an audit and found that the Emergencies Ministry had violated the law. Each tourist visiting the Exclusion Zone paid approximately $100 for entry, and the Prosecutor General sought an accounting of the money earned from these trips, arguing that it was public funds.

In February 2011, it was revealed that birds living around the site of the Chernobyl accident had brains that were 5 percent smaller, which was directly linked to residual background radiation. A study was conducted on 550 birds from 48 species that inhabited the region.

On November 25, 2011, a Kiev court banned tours to the Exclusion Zone. It took over a year to resolve the dispute, and eventually, Pripyat was reopened to tourists, albeit at an increased price.

In December 2017, a Ukrainian-German company named Solar Chernobyl announced the construction of a massive solar plant in the Exclusion Zone. The one-megawatt power plant was built near the destroyed reactor number 4 and fitted with 3,800 photovoltaic cells. The Ukrainian governmenthas stated that further development is planned for the area.

In July 2019, the Ukrainian president, Volodymyr Zelenskyy, announced that the Chernobyl site would become an official tourist attraction. The number of visitors sharply increased following the release of an HBO mini-series about the accident.

In April 2020, forest fires spread through the Exclusion Zone, causing an increase in radiation due to the release of caesium-137 and strontium-90 from the ground and vegetation. The residents of Kyiv received an increased radiation dose of 1 nSv.

The Exclusion Zone will not be safe for human habitation for the next 24,000 years. However, animals, such as boars, wolves, beavers, and bison, are thriving in the area. This is believed to be due to the absence of human activity.

Discussion

Chernobyl was an accident that should not have happened. We have those in the United States too, where many factors come together to create a disaster. For Chernobyl, the factors were numerous, such as the Soviet system, human error, design flaws, and a lack of a safety culture.

Chernobyl, Three Mile Island, the Challenger explosion, and the Bhopal disaster have all been used as case studies. These have been studied to determine the root causes of these types of disasters. Sleep deprivation and mismanagement are often cited as issues.

Honesty was not a part of the Soviet system. The first statement from Makukhin to the Communist Party (Anatoly Mayorets) had several falsehoods. In an urgent report to Anatoly Mayorets, First Deputy Minister of Energy and Electrification of the USSR, A.N. Makukhin stated that an explosion occurred after the reactor had been stopped. He also stated that the fire had been put out by 3:30 AM. He mentioned only that the roof and parts of the wall paneling of the reactor compartment, panels of the roof in the machine hall, and a unit of the auxiliary systems of the reactor compartment had collapsed. He mentioned the fire but failed to mention the damage to the reactor itself. He also made the vague statement of measures being taken to eliminate the consequences and investigate the incident. Mayorets had forbidden his public servants from telling the truth to the press after the accident. At the July 3, 1986, Politburo meeting, Mikhail Gorbachev stated that he recommended a reprimand for Mayorets, even though he stated that he should be fired.

When interviewed for a 2006 documentary, Mikhail Gorbachev (former Soviet president) stated that he got the call about 5 AM, saying that there had been an accident. He stated that the first information was of an accident and a fire, and he had been told that there was no explosion. He pointed out that the consequences of such false information were particularly dramatic. Gorbachev stated that he was specifically told that everything was safe and sound, including the reactor. He also remembered that the specialists were unable to give him any information for the first couple of days, even though they were in session awaiting information as well as demanding it.

Gorbachev mentioned that there had been accidents in the Soviet Union before, and the information had been kept secret. Although they had accidents before, never one of the scope of the one at Chernobyl in 1986. Gorbachev also made note of the fact that Sweden was the one that alerted them in Moscow to the extent of the accident. Thus, the Soviet government was

forced to admit they had an accident. They decided in Moscow that it was essential that the facts be reported to them from then on. He called the KGB and told them to follow everything that was happening, including the conversations of the scientists. Gorbachev wanted all of the information delivered to him personally from that point on.

The Soviet Union's initial investigation put most of the blame for the accident on the operators and management. Later, the IAEA and Ministry of Atomic Energy found that reactor design flaws and how the operators were informed of safety information were more significant factors in the accident. The operators were found to have deviated from operational procedures and changed test protocols at the moment, so human error was a contributing factor.

The accident triggered a change in the hard-line policies of the Soviet Union. This fact was admitted by Soviet Defense Minister Marshal Dmitri Yazov in 1991. He stated that the accident demonstrated that nuclear war is unthinkable. The logic behind this was based on a nuclear power plant being a device that is designed not to explode but did explode. Think of the probability of all the devices that are designed to explode and what they could do.

In examining the causes of the accident, there was a mixture of bad design, bad regulation, bad operation, bad management, and a lack of a safety culture. Those have not changed since the accident. What has changed is the weight put on each factor. Just after the accident, more blame was placed on the operators. Around 1991, the shift was made to the design of the reactor being more to blame for the accident. The reactor had several design flaws. Among these flaws were a positive void coefficient, control rod design, operation beyond safe conditions, and the emergency cooling system.

One of the design issues was the positive void coefficient. If there is an accidental increase in power, the temperature in the core rises, as well as the steam fraction in the cooling water. The water density is decreased, as well as the absorption of neutrons by the water (leaving more neutrons available for chain reactions), which further increases the power. The instability is compensated for under normal conditions since there will be control rods in the core giving a fuel coefficient that is always negative. When nearly all of the control rods are pulled out, the value ofthe positive void coefficient is greatly enhanced, which can overcome the negative fuel coefficient, making the power coefficient positive.

The control rod design was another contributing factor among the design issues. The control rods for the RBMK-1000 at Chernobyl had graphite tips. Instead of causing an immediate

decrease in reactivity as the control rod is inserted, reactivity is increased briefly. This is because graphite is the moderator in the RBMK-1000. This is normally compensated for by maintaining the required minimum number of control rods (25) inserted to the point where additional insertion causes a strong negative impact on the total reactivity.

The RBMK-1000 reactor can operate beyond safe conditions by the decision of the operator. To give an example, almost all of the control rods were withdrawn, below the minimum 25, without being questioned.

Another issue is the emergency cooling system. It protects against the breakage of a coolant pipe. However, it only protects against the breaking of one coolant pipe at a time. If multiple pipes break, the reactor is left unprotected.

Management had shortcomings in their system that contributed to the disaster. One of these issues was failing to study and communicate the existence of precursors to the accident to engineers and operators. One of these precursors was a partial meltdown at the Leningrad NPP in October 1975. Another was an accident in reactor 1 of Chernobyl in September 1982. Management also failed to inform the engineers and operators of design weaknesses.

The regulatory and procedural problems also contributed to the accident. There was not a clear set of operating rules. They did not ensure that unusual procedures (e.g., safety tests) were discussed in advance. Discussions would likely include what-if type of questions. A full safety analysis (risk analysis) was not conducted.

Operating problems that existed at the Chernobyl NPP also contributed to the accident. Operating with only seven control rods in the core, carrying out the test when the reactor was not stable, and switching off six different safety systems were among the issues.

When the Soviets sent representatives to Vienna on August 25-29, 1986, the head of the Soviet team was Dr. Valery Legasov. Dr. Legasov stated that it was clear that the Soviet Union paid too little attention to the man-machine interface. Deceptively, he let many observers believe that human error was the sole cause of the accident. Dr. Legasov admitted this in October 1986 to the Soviet Academy of Sciences when he stated, "I did not lie in Vienna, but I did not tell the whole truth."

Dr. Wilson and a Stone & Webster Engineer were able to con their way into seeing the Russian delegation. They entered the room where Dr. Legasov and his team were meeting, stating they had measurements of radiation in Europe and wanted to compare them with measurements taken in the USSR. Dr. Wilson thought that it could have been his persistence in trying to understand the truth without recrimination that helped Legasov and his colleagues turn away from the Soviet policy of secrecy. Two Soviet experts came out of their meeting to discuss their measurements and calculations with Dr. Wilson and the Stone & Webster Engineer. After this meeting, the secrecy quickly restored itself.

There were restrictions on the flow of information from and to scientists in the Soviet Union. Dr. Demin removed six pages from the official report before the IAEA meeting in August 1986. These pages described radioactive contamination approximately 100 km northeast of Chernobyl in Belarus and Russia. Demin stated that he was told by Legasov to remove these pages on orders from higher up. The report to the IAEA in Vienna made by the Soviet experts was declared secret within the USSR. Geiger counters were not available to the public in the USSR. For example, they were confiscated from citizens in Pripyat after the accident. Publication of "unauthorized" radioactivity measurements or lectures using foreign sources of information about radioactive contamination was forbidden. Radiation was also forbidden to physicians in mentioning a diagnosis in Ukraine and Belarus. They also clamped down when private individuals in Belarus appealed to children not to drink milk in early May 1986. Soviet officials did not want to cause a panic.

Legasov was interviewed by Pravda in 1987, shortly before his death, and discussed the mismanagement of the disaster. He described the disaster as the "apotheosis and peak of the economic mismanagement in our country over decades." Legasov stated that there was not a single team in the Soviet Union that had "even the slightest competence" to solve the safety problems. He even stated that the older and more experienced personnel in the industry were "set in their ways" and that new approaches and suggestions were greeted with hostility. He stated that even the directors of the power stations seemed unconcerned about any danger.

Legasov stated to Pravda that not only were the plants mismanaged, but the emergency operations were also mismanaged. When he got to Kiev, the leaders of the Ukraine SSR had no information other than "things are bad". There were equipment shortages, such as respirators andThe language and grammar in the provided text are generally correct. However, there are a few minor adjustments that can be made to improve clarity and readability. Here is the revised version:

The design of the control rods was another contributing factor among the design issues. The control rods for the RBMK-1000 at Chernobyl had graphite tips. Instead of immediately decreasing reactivity when inserted, the reactivity briefly increased. This is because graphite serves as the moderator in the RBMK-1000. To compensate for this, it is necessary to maintain a minimum number of control rods (25) inserted until further insertion negatively impacts the total reactivity.

The RBMK-1000 reactor can be operated beyond safe conditions at the operator's discretion. For example, almost all of the control rods were withdrawn, going below the minimum of 25, without any questions being raised.

Another issue relates to the emergency cooling system. While it provides protection against the rupture of a single coolant pipe, it is not designed to handle the simultaneous breakage of multiple pipes, leaving the reactor unprotected.

The management system had shortcomings that contributed to the disaster. One of these issues was the failure to study and communicate the existence of precursors to the accident to engineers and operators. One of these precursors was a partial meltdown at the Leningrad NPP in October 1975. Another was an accident in reactor 1 of Chernobyl in September 1982. Additionally, management failed to inform the engineers and operators about design weaknesses.

The accident was also influenced by regulatory and procedural problems. There was a lack of clear operating rules, and unusual procedures (such as safety tests) were not adequately discussed in advance, including potential what-if scenarios. A comprehensive safety analysis (risk analysis) was not conducted.

Operating problems at the Chernobyl NPP further contributed to the accident. These included operating with only seven control rods in the core, conducting the test when the reactor was unstable (instead of at the intended thirty percent power level, it was actually at five percent and in an unstable state), and deactivating six different safety systems.

During the meeting in Vienna on August 25-29, 1986, led by Dr. Valery Legasov, head of the Soviet team, it became clear that the Soviet Union had not given sufficient attention to the man-machine interface. Dr. Legasov deceptively allowed many observers to believe that human

error was the sole cause of the accident. However, in October 1986, he admitted to the Soviet Academy of Sciences that he had not lied in Vienna but had not provided the complete truth.

Dr. Wilson and a Stone & Webster Engineer managed to gain access to the Russian delegation. They entered the room where Dr. Legasov and his team were meeting, claiming to have radiation measurements from Europe that they wanted to compare with those taken in the USSR. Dr. Wilson believed that his persistence in seeking the truth without blame helped Legasov and his colleagues move away from the Soviet policy of secrecy. Two Soviet experts came out of the meeting to discuss their measurements and calculations with Dr. Wilson and the Stone & Webster Engineer. However, the secrecy quickly resumed after this meeting.

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Legasov stated to Pravda that not only were the plants mismanaged, but the emergency operations were also mismanaged. When he got to Kiev, the leaders of the Ukrainian SSR had no information other than "things are bad." There were equipment shortages, such as respirators

and radiation meters. He described firefighting operations as also badly organized. His efforts to publicize the neglect of safety training after the accident seemed to fall on deaf ears.

Legasov's ideas were not completely ignored; they were just not taken seriously by the right people, namely his fellow scientists. Mikhail Gorbachev delivered a speech on Soviet television on May 14, 1986, where he discussed the lessons of Chernobyl and made his first public comments about the incident. He stated that the "lesson of Chernobyl lies indisputably in the fact that further development of the scientific and technical revolution will require questions of the reliability of technology and its safety, questions of discipline, order, and organization to be accorded prime importance. The highest standards are necessary everywhere and in everything."

As mentioned before, there were other accidents with the same type of reactor at Chernobyl and Leningrad. There were also other accidents in the Soviet Union, such as high radiation doses at Chelyabinsk (military) and the Kyshtym accident. A common factor in all of these accidents is the failure of the Soviet political system to manage technology safely. This failure is partially due to the prevalent secrecy in Soviet society, where society existed in compartments with little or no communication between them, according to Dr. Wilson.

The secrecy of the Soviet Union was not conducive to safety. When secrecy exists, one can only learn from their own mistakes instead of the mistakes of others. Anatoly Dyatlov stated in his testimony that he did not know about previous incidents at other plants with the RBMK-1000. Residents of the USSR would understand this secrecy, but it is counterintuitive to someone in the United States. The INSAG-7 report discussed the lack of communication and exchange of information as contributory factors. The disaster forced the Soviet government to become less secretive.

Finally, I should mention Vaughan's Normalization of Deviance. Diane Vaughan wrote about the effect on the Space Shuttle Challenger, which experienced a disaster in January 1986, just months before the Chernobyl disaster. In 1996, Vaughan described social normalization of deviance as people within an organization becoming so accustomed to a deviation that they don't consider it deviant, even when they exceed their own rules for elementary safety. The Shuttle Solid Rocket Booster O-ring received criticality 1 waivers despite a design goal of no joint failures. Joint material erosion and blow-by were accepted as risks in the program. It was ultimately an O-ring failure that led to the Challenger disaster. Warnings in the Challenger disaster were ignored, as they were months later in the Chernobyl disaster.

The normalization of deviance can often lead to groupthink. There is a tendency to rationalize shortcuts while under pressure, especially when nothing bad happens. The lack of negative outcomes tends to justify trusting past success instead of objectively assessing risk. The physicist Dr. Richard Feynman compared this practice to playing Russian Roulette.

After the accident in 1986, the International Nuclear Safety Group (INSAG) issued the INSAG-1 report. Since it contained a lot of misleading Soviet material that biased towards operator error, a report had to be released to amend it, with the primary attention given to the reasons for the accident. The INSAG-7 report was issued in 1992 as part of the IAEA Safety Series. INSAG-7 presented "new" information that had become available, such as design flaws (e.g., control rod design). The report shifted the blame away from operator error and towards design flaws, particularly graphite-tipped control rods. The INSAG-7 report also pointed out that operator actions identified as regulation violations in the 1986 report were not violations, as there were no such regulations in place at the time.

The INSAG-7 report highlighted numerous problems as contributing factors. These problems included:

1) The plant fell short of the safety standards that were in effect when it was designed and even incorporated unsafe features.
2) There was insufficient safety and risk analysis.
3) There was a lack of attention to conducting an independent safety review.
4) The operating instructions did not have sufficient safety analysis.
5) There was inadequate and ineffective exchange of important safety information between operators and between designers and operators.
6) The operators did not have adequate knowledge of the safety aspects of the plant.
7) There was a lack of respect for operational and test procedures on the part of the operators.
8) There was an insufficient regulatory regime that was unable to counter pressures for production.
9) There was a general lack of a safety culture in nuclear matters extending from the local level to the national level.

Timeline of Major Events Around Chernobyl Disaster

Event	Date	
Construction of the town of Pripyet begins	1970	
Discussions in Kiev about the type of nuclear power plant to be built at Chernobyl	1972	
The filling of the cooling water reservoir for the Chernobyl Nuclear Power Plant is started	1976	
The Chernobyl Nuclear Power Station begins supplying power	26 Sep 1977	
Pripyat is officially declared a city	1979	
Partial core meltdown occurs in reactor number 1	9 Sep 1982	
Reactor number 4 begins operations	20 Dec 1983	
The plant's operations are reported in the news media	22 Dec 1983	
Soviet official is quoted as saying that the odds of a nuclear meltdown are "one in 10,000 years"	Feb 1986	
Article written by Ms. Lyubov Kovalevska about the failures at Chernobyl	27 Mar 1986	
Operators begin reducing power in reactor number 4 in preparation for a safety test	25 Apr 1986	1 AM
The emergency core cooling system is disabled for reactor number 4 to keep it from interfering with the safety test	25 Apr 1986	2 PM.
Operators receive permission to continue with the test and shutdown.	25 Apr 1986	11:10 PM
Aleksandr Akimov takes over as shift leader	20 Apr 1986	12:00

		AM
The power drops far below to where the reactor is considered stable	26 Apr 1986	12:28 AM
Power stabilizes at a lower level than preferred for the test	26 Apr 1986	1 AM
Plant supervisors order the test to proceed	26 Apr 1986	1 AM
And the emergency shutdown system and other safety features are turned off	26 Apr 1986	1 AM
Operator blocks automatic shutdown due to low water level and loss of both turbines	26 Apr 1986	1:19 AM
The caps to the fuel channels are seen jumping in their sockets	26 Apr 1986	1:21 AM
The test officially begins and an unexpected power surge occurs	26 Apr 1986	1:23 AM
An operator presses the emergency shutdown button (AZ-5), but the control rods get jammed while entering the core	26 Apr 1986	1:23 AM
The first explosion occurs, followed quickly by a second explosion	26 Apr 1986	1:23 AM
Akimov calls the fire department	26 Apr 1986	1:26 AM
The first firefighters arrive, unprepared for radiation	26 Apr 1986	1:28 AM
New teams of firefighters arrive	26 Apr 1986	1:45 AM
Dyatlov orders Akimov to feed water to the reactor	26 Apr 1986	2 AM
An emergency meeting of local Soviet officials occurs and decide to block cars from entering or exiting Pripyat	26 Apr 1986	2:15 AM
Bryukhanov arrives at the bunker under the administrative block	26 Apr 1986	2:30 AM

Bryukhanov calls Maryin, Deputy Secretary for the Nuclear Power Industry	26 Apr 1986	3 AM
Akimov is contacted by fire brigade commander, Telyatnikov. Akimov sends a dosimetrist	26 Apr 1986	3:30 AM
Fomin arrives at the control room	26 Apr 1986	4:30 AM
Dyatlov gets sick in the civil defense bunker after showing Bryukhanov the final printouts of the reactor state before the explosion	26 Apr 1986	5 AM
Reactor number 3 is shut down under the orders of officials	26 Apr 1986	5 AM
Anotoly Sitnikov replaces Dyatlov and is ordered by Fomin to survey the reactor from the roof of unit number 3	26 Apr 1986	5 AM
Akimov is replaced in the control room, but stays at the plant with Toptunov	26 Apr 1986	6 AM
All fires have been extinguished except for a blaze in the reactor core	26 Apr 1986	6:35 AM
New shift clocks in to all four units	26 Apr 1986	8 AM
Anotoly Sitnikov returns to the control room and reports to Fomin and Bryukhanov that reactor number 4 had been destroyed	26 Apr 1986	10 AM
A government committee was established to be headed by Valery Legasov	28 Apr 1986	8 PM
General Pikalov rams the gate of the plant with a truck outfitted with a radiation detector	27 Apr 1986	7 AM
Soviet helicopters begin the process of dumping sand, clay, boron, lead, and dolomite into the burning core	27 Apr 1986	10 AM

Reactors 1 and 2 are shut down	27 Apr 1986	
Soviet officials begin evacuating the residents of Pripyat, as well as nearby towns	27 Apr 1986	2 PM
Air monitors in Sweden detect a large amount of radiation that is traced back to the Soviet Union	28 Apr 1986	
Broadcast made of a statement issued by Tass that there had been an accident at Chernobyl nuclear power station.	28 Apr 1986	8 PM
United States officials are provided their first look at the disaster by spy satellite	29 Apr 1986	
Tass carries another government statement to deny western reports about mass casualties, stating 2 dead and 197 hospitalized, with radiation levels decreasing	30 Apr 1986	
May Day celebrations take place in Kiev despite the radiation release continuing	1 May 1986	
An attempt to cool the reactor is made by pumping liquid nitrogen underneath it	4 May 1986	
First film footage of Chernobyl is shown on Vremya	4 May 1986	
IAEA delegation headed by Hans Blix arrives in Moscow	5 May 1986	
Construction begins on an embankment on the Pripyet river	5 May 1986	
The core fire has burned itself out and radioactive emissions drop sharply	6 May 1986	
Soviet officials' close schools in Kiev and Gomel	6 May 1986	
Pravda carries the first extensive report on the accident	6 May 1986	

Tass report that residents of Kiev are trying to leave the city	7 May 1986
Radioactive water is drained from the basement under the core	8 May 1986
The process of pouring concrete under the reactor is begun	9 May 1986
Aleksandr Akimov dies of radiation he received	10 May 1986
IAEA states that the reactor fire is out	10 May 1986
Pravyk dies of acute radiation syndrome	11 May 1986
Vasily Ignatenko dies at Moscow Hospital 6	13 May 1986
Toptunov dies of acute radiation poisoning	14 May 1986
Mikhail Gorbachev speaks publically about the incident for the first time	14 May 1986
Design of the sarcophagus begins	20 May 1986
A Soviet government committee orders the distribution of iodine preparations	23 May 1986
The design of the sarcophagus is started	24 May 1986
Politburo Meeting	3 Jul 1986
Anatoly Mayorets states to his civil servants that they are forbidden to tell the truth to the media about the Chernobyl accident	18 Jul 1986
IAEA hosts a conference and blame the accident on several factors	25-29 Aug 1986
Reactor number 1 is restarted	29 Sep 1986

Reactor number 2 is restarted	9 Nov 1986
The sarcophagus is completed	14 Dec 1986
Russian filmmaker, Vladimir Chevchenko, dies due to radiation sickness from early response to the disaster	Mar 1987
Reactor number 3 is restarted	21 Apr 1987
Trial begins for Dyatlov, Fomin, and Bryukhanov	6 Jul 1987
Valery Legasov commits suicide	27 Apr 1988
The Soviet Union launches a special stamp to commemorate the accident	26 Apr 1991
Ukraine declares its independence from the Soviet Union	24 Aug 1991
Competition held for a replacement for the sarcophagus	1992
A French government minister admits to being misled about the impact of the disaster	25 Apr 1996
The Head of the Belarus Radiation Medicine Institute discusses deformations of reproduction systems	Mar 2000
Unit 3 is shut down (last working reactor)	15 Dec 2000
The New Scientist Magazine quotes two independent scientists in the UK who accused the IAEA and the WHO of downplaying the impact of the disaster	6 Apr 2006
Greenpeace report on the number of cancer cases released	18 Apr 2006
Study of birds around Chernobyl released	23 Apr 2007

Report on a story of New York based medical specialists	Jun 2007
The contract for the New Safe Confinement is signed	17 Sep 2007
Power plant roof collapses due to heavy snowfall but it does not affect the sarcophagus	13 Feb 2013
The two halves of the New Safe Confinement are brought together	24 Jul 2015
Ukrainian-German company announces the building of a massive solar plant	Dec 2017
It is announced by the Ukrainian president that the Chernobyl site would become an official tourist attraction	Jul 2019
Forest fires spread through the area of the Exclusion Zone	Apr 2020

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