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Nuclear Power—Benefit or Threat? Nuclear Engineering and Technology Examination

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Abstract

As the globe struggles with climate change and energy security, nuclear power is back in the news. This low-carbon, high-output alternative to fossil fuels can stabilize electrical networks, say supporters. Critics say catastrophic accidents, radioactive waste, high costs, and technology spread are risks. When the earth is warming quickly, and energy demand is expanding worldwide, finding reliable, low-carbon energy sources is more critical than ever. Nuclear power is a potential yet contentious option. Nuclear energy can generate a lot of electricity with little greenhouse gas emissions; thus, some governments and experts see it as a crucial aspect of leaving fossil fuels. However, Chernobyl, Fukushima, and Three Mile Island still influence public opinion and policy. Radioactive waste, high building costs, and the threat of nuclear war make its role in the energy mix harder. This article critically examines nuclear power's place in today's energy landscape and its risks and possibilities to save the globe. The essay examines new technologies, past incidents, safety rules, waste management plans, and public opinion to provide a balanced view. Nuclear power may help transition to a sustainable energy future, despite its concerns. However, tough standards, openness, and new ideas must steer this evolution. The essay discusses nuclear engineering and technology.

Keywords: Climate change, radioactive waste, energy security, nuclear safety

INTRODUCTION

Nuclear power is one of the most significant energy sources. Some see it as a savior, a strong solution to climate change and energy requirements, while others see it as a threat due to accidents, waste, and weaponization. You must know their pros and cons.

Nuclear fission power stations may shrink, grow, or be replaced by compact modular reactors in various countries. Early nuclear physics breakthroughs and business needs have driven nuclear energy utilization. Modern life has resulted in new safety rules and waste issues. Recent concerns include fuel cladding vulnerabilities and reactor design complexities. These weaknesses threaten safety and necessitate new rules. Small modular reactors may be required if large reactors remain in operation. Scientific and technological uncertainties increase prices, delays, and project cancellations. Anti-nuclear groups use unresolved challenges to change legislation and may eliminate nuclear technology [1].

A 1,000-MW nuclear power plant emits less CO_2, methane, and nitrous oxide than a fossil fuel facility of the same size. Nuclear power is greener than conventional power. The massive amount of electricity that a nuclear station uses might be affected by even minor plant issues. These delays also hurt the company's economy. Emerging countries aspiring to considerably improve their energy portfolios should consider nuclear power [2].

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VALUE OF THE STUDY

This study is essential because it examines nuclear power's potential to solve energy and climate issues and its potential risks to the environment, health, and global politics. To make informed decisions in times of worsening climate change, energy security concerns, and rapid technological change, it is crucial to understand the role of nuclear energy.

This study examines the pros and cons of nuclear power in promoting a balanced and evidence-based debate. This report is crucial for scientists, politicians, environmentalists, and the public who must make critical sustainable energy decisions.

This initiative seeks to improve energy planning, technology, and the benefits and risks of nuclear power.

OBJECTIVES OF THE STUDY

Discovering how nuclear energy generates power, reduces carbon emissions, and ensures energy safety. To identify and research nuclear power issues and risks Investigate nuclear accidents, radioactive waste, environmental impacts, and nuclear proliferation. Assess nuclear energy's climate change mitigation potential. Compare nuclear power to fossil fuels and renewables for sustainability and environmental impact. Examine nuclear technology's latest advances and safety measures. Consider Small Modular Reactor(SMRs) and waste management innovations. To examine public opinion on nuclear energy and policy implications Discover how governments, communities, and international organizations view and manage nuclear energy. To fairly answer whether nuclear power should be pursued, limited, or phased out Make energy policy recommendations after assessing risks and benefits.

NUCLEAR ENERGY HISTORY

The nuclear energy history shows how fission and uranium reactor technologies have advanced. These technologies promise inexpensive, clean, and long-lasting electricity. The story begins with the discovery of the atomic nucleus in 1911 and continues through key scientific and technological advances. The future of nuclear power depends on technological issues and opportunities.

Scientists studied the atomic nuclear structure in the early 1900s. Uranium fission, which powers nuclear energy, was discovered by Otto Hahn and Fritz Strassmann at the Kaiser Wilhelm Institute of Berlin in 1938. Slowing neutrons increases fission processes, according to Enrico Fermi et al. In 1941, Enrico Fermi and Leo Szilard initiated the first controlled nuclear chain reaction in Chicago. Wigner and Weinberg designed the first usable reactors in Oak Ridge, Tennessee. These designs were used to manufacture nuclear materials and test future nuclear power methods.

Mass uranium enrichment, led by Francis Perrin et al., ended in Oak Ridge, Tennessee. The modest graphite-moderated X-10 reactor of Oak Ridge was built by Henry D. Smyth for nuclear research. The 1964–1965 discovery of the cosmic microwave background by Arno Penzias and Robert Wilson helped explain the origin of the universe. It did not lead to nuclear power, but helped people grasp the universe through nuclear science. Admiral Hyman Rickover designed and built the first pressurized water reactor because he loved nuclear power. Nautilus, the first atomic submarine, required this reactor.

In 1969, Nixon urged the use of Navy propulsion technology for civilian power. The 200-MW pressurized water reactor became the first commercial reactor on February 25, 1967. Nuclear power was cheap, clean, and efficient, and it increased swiftly in the 1970s.

The founding of a large industry to construct reactors for submarine propulsion, atomic weapons research, and long-term power generation barely covers a century of nuclear fission enterprises.

MAKING NUCLEAR ENERGY

Nuclear fission generates energy from uranium and plutonium [2]. Steam is produced by water-absorbing fission heat. Different reactors were used, including light water, heavy water, and gas cooling. Light water reactors utilize normal water to cool and regulate reactions. Heavy-water reactors cool and regulate reactions with heavy water and enrich uranium fuel. The reaction is cooled by graphite, carbon dioxide, or helium in a gas-cooled reactor [3].

Nuclear Fission

Nuclear fission releases a large amount of binding energy per nucleon when a massive nucleus breaks apart [4]. The method produces 200 MeV of energy per fission for uranium or plutonium, or 80 million Gigajoule per kg, which is ten million times more energy than fossil fuels. Chain reactions are unlikely because one neutron cannot start a fission reaction, and one nucleus usually only creates one or two neutrons. A chain reaction requires fission to average two or more fissions. This chain reaction is a large energy source because it produces approximately as much energy as fission [1]. A subcritical reaction can be sustained by an external neutron source as determined by the geometry of the fissile material.

The critical mass is the minimum fissile material required for a neutron to induce multiple fissions. The critical mass of a system depends on its temperature, pressure, form, neutron absorbers, and moderators. Nuclear weapons should achieve a critical mass in microseconds, causing massive explosions. In nuclear reactors, rapid criticality is undesirable; therefore, controlled fission continues. A chain reaction is unlikely because natural uranium has only 0.7% uranium-235 isotopes. Many countries have added uranium-235 to 7% of natural uranium, which works in reactors. Uranium-235 fissions release neutrons and fission products. Another uranium-235 nucleus receives or releases neutrons. Plutonium-239 fissions initiate the chain reaction with three neutrons. Many isotopes with too few or too many neutrons break down, releasing ionizing radiation and reducing the neutron/proton ratio to beta stability. Shielding and distancing are the best strategies to protect against harmful radiation and ensure nuclear safety.

Types of Nuclear Reactors

Technologically advanced nuclear reactors have been grouped into generations. The commercial reactors used were Generation II. Most experimental facilities and unique designs (some used as prototypes or specialized power plants) are Generation IV [1, 5]. The core of the reactor underwent chain nuclear fission. Each reaction generates a large amount of heat, but the coolant of the loop moves to a secondary cycle to generate electricity. The underlying notion has not changed, but developing such complex equipment places a lot of burden on design and production teams, especially when it comes to ensuring that parts are trustworthy, can tolerate extreme conditions, and are coupled smartly. The key concepts are hanging core and pool arrangements. The first features a core hanging from the top structure, while the second has a vast underground pool around the center. No major changes are expected in the near future, because each generation has introduced modest traits.

Generations change primarily because of the reactor core material. Generation III facilities use liquid water, whereas Generation IV facilities use supercritical water. The latter strategy improves the cycle efficiency owing to the greater inlet temperature and pressure. Global research organizations are trying to make Generation IV pools operate, but they have not found a solution. People want waterless coolants.

BENEFITS OF NUCLEAR ENERGY

Nuclear energy is the most important technology for addressing future electricity needs without increasing CO_2 emissions [6]. Hydrogen production, heat processing, and drinking water supplies are being developed for sustainable energy. Industrial civilization requires increasing energy supplies. People have reconsidered nuclear energy as a long-term source. The world has sufficient nuclear fuel for the 21st century and beyond, especially if fast-breeder reactor technology is fully developed. Fast-breeder reactors use uranium-238 and thorium to generate 60 times more energy per kilogram [3]. India, China, and Russia are planning reactors, and the Generation IV International Forum has selected several fast-breeder designs for joint research to improve the economy, safety, proliferation resistance, and security by 2030. This indicates a renewed interest in these systems. Nuclear power may produce 5% of the 21st-century energy with 4 million tons of fuel and 2% annual growth. If capacity and technology improve, 20% of energy may be produced. It could become a major energy source later in this century or the next, with better discovery, extraction, and reactor designs.

Nuclear energy provides 14% of the world's electricity and may help countries grow, secure energy, and choose greener energy sources. A properly developed nuclear expansion program requires early commitment, infrastructure, and a controlled market. Developing countries seeking energy security, local industrialization, and competitive power generation will find this enticing. In many poor countries, people must overcome their fears about the nuclear fuel chain moving beyond uranium mining and enrichment to realize its potential. Despite being clean and long-lasting, nuclear energy remains contentious [2]. The UN lists nuclear technologies as one of the eight.

Low Greenhouse Gas Emissions

Greenhouse gas emissions were considered when comparing energy sources. Burning fossil fuels releases brown ash, carbon dioxide, nitrogen oxides, sulfur dioxide, and minor amounts of heavy metals, warming the world. Nuclear power produces less radiotoxicity than coal-fired power. This is because uranium replaced coal. Nuclear reactors do not release nitrogen oxides, sulfur dioxide, or mercury compounds such as fossil fuels. Nuclear power reduces carbon dioxide emissions by thousands of kilograms per megawatt-hour. If all nuclear power plants used coal-fired power plants, annual carbon dioxide and sulfur dioxide emissions would rise by 1.6 billion and 5 million tonnes, respectively. From 1973 to 2012, the global power industry's sulfur dioxide and nitrogen oxide emissions decreased by 71% and 60%, respectively. Uranium fission generates electricity in the absence of fuel. Fission waste is stored in well-protected facilities to prevent pollution [6].

In recent decades, reactor designs and facility operations have been steadily altered. Light-water reactors (LWR), heavy-water reactors (PHWR), fast-breeder reactors (FBR), high-temperature gas-cooled reactors (HTGR), and molten-salt reactors are being considered for future nuclear projects. Recent designs have been simplified and made easier to use. Burning more nuclear fuel makes it easier to utilize and reduce waste. Fourth-generation molten-salt reactors are the safest because they have built-in safety systems. They used molten salt instead of water as a coolant to operate at atmospheric pressure and avoid steam explosions [7].

Safety of Energy

Many countries have attempted to stabilize their energy sources by importing them for 60 years. France receives 80% of its electricity from nuclear power, thus reducing supply issues [6]. Only 25% of Germany's power came from nuclear power. It imports fossil fuels and renewable energy from other countries. Approximately 40% of the EU electricity comes from nuclear fission reactors. Energy security is a top priority in many countries [8]. Many expect global demand is expected to triple by 2050, but political instability and low investment may limit the supply. Economics, the environment, and energy security are the top priorities.

Economic Considerations

Recent economic studies [9] have examined the advantages and disadvantages of nuclear power. The construction and operation of Nuclear Power Plants (NPPs) require many technical experts. Building one unit requires a large amount of concrete, steel, plumbing, and electrical connections, which is why power generation is expected to be expensive. However, industry strengthens the economy and society by producing steady jobs, boosting economic growth in particular areas, and increasing GDP.

When properly used, nuclear energy is environmentally safe. Nuclear power facilities emit little energy, except for water vapor. This had little effect on the environment. Compared with other natural and anthropogenic sources, nuclear power plants have little radiation. They do not release greenhouse gases such as coal, oil, or gas thermal stations. New methods of processing and disposing of spent fuel can practically eliminate radioactive material emissions and reduce risk. When properly used, nuclear energy is safe, long-lasting, and high-tech.

The political and economic circumstances in Central and Eastern Europe make nuclear power even more crucial for economic growth and safety [10]. Ukraine uses the most nuclear power in the region, but decreasing its economic dependence on Russia will require a lot of money and stringent restrictions, even though the war continues. Even with groundwater pollution, earthquake risk, and airborne contamination, the neighborhood supports nuclear energy politically, economically, and socially. Nuclear energy debates generally disregard environmental issues that are crucial for long-term growth. Repairing and extending the lifespan of many reactors is crucial because nuclear production is predicted to increase by 37–110% by 2035. The scientific accord underlines that nuclear energy can help Eastern Europe recover and grow economically, owing to popular enthusiasm and trust. To capitalize on these opportunities, investments must be well managed and public backing enhanced by a robust legislative framework to ensure that the region's nuclear business grows safely and effectively.

NUKE ENGINEERING

The use of neural networks, fuzzy logic, and evolutionary algorithms to monitor, diagnose, and operate nuclear power reactors and their parts is a promising subject. Monitoring and diagnosing nuclear power plants, check valves, instrumentation systems, and rotating machinery is possible. Sensor surveillance, calibration verification, plant transients and problems, efficiency improvement, vibration analysis, loose part monitoring, and adaptive and optimal control were used. Several applications demonstrate how neural networks, fuzzy systems, and evolutionary algorithms operate together [23].

NUCLEAR SCIENCE

Monitoring and estimating material lifespans in aging nuclear power facilities are crucial. Cables that connect reactor control systems are essential for safe operation and emergency shutdown. Testing this cabling for suitability is a major concern; however, there is no standard method. A "toolbox" comprising chemical, electrical, and mechanical testing is used instead. However, this work has several flaws and must be changed. This is still being investigated to identify the optimal methods. Cable monitoring aims to link the insulation condition to possible Design Basis Event (DBE) survival.

NUCLEAR POWER RISKS

Nuclear Energy Risks Include Accidents, Waste, and Proliferation

Many researchers believe that nuclear plant accidents are one of the main risks of this energy. Although nuclear accidents have not killed anyone, Fukushima, Three Mile Island, and Chernobyl have proven the deadly of the technology. No major nuclear reactor accidents have occurred since the Chernobyl earthquake. This proves their safety and was missed because of a previous calamity. The implemented procedures minimize damage, even though problems cannot be ruled out [11].

Radioactive waste from nuclear plants is another concern. The material is maintained outside the factory for individuals to use indefinitely, raising security and safety concerns. Owing to its high energy-to-mass ratio, this material produces less waste. However, finding long-term solutions to such massive amounts of toxic waste is crucial. Thus, public perceptions of threats may differ from those of professional assessment.

Nuclear Mishaps

Past nuclear accidents were risk factors. Modern stations undergo many design updates to improve their security following major events. Legislation requires acceptable risks and manageable results. All modern plants have multiple levels of protection and passive safety devices that are activated when something goes wrong. Chernobyl was caused by design defects, inadequate operations, and unanticipated events. The fuel exploded, and the core melted because the power of the reactor exceeded expectations. Mistakes, usually induced by operator errors or experimentation pressure, contributed to Chernobyl. Because current approaches do not require operators to intervene quickly, safety systems can operate independently for 30 minutes. Despite this comprehensive review, human errors cannot be eliminated. Serious accidents remain the greatest risk, but they have decreased over time. Core stockpile discharge has the greatest meltdown risk. The reasons a facility is developed vary over its decades-long life, changing terrorist attack risks change. Massive physical destruction, weapons, dirty bomb ingredients, large economic repercussions, and attention are common motives. Nuclear plants are attractive targets because they may cause considerable damage and fear of radiation. Regular structures, chemical factories, dams, and transportation lines have similar reasons. Site security and facility design are countermeasures [12].

Handling Radioactive Waste

The nuclear energy business struggles with radioactive waste. Partitioning and recycling, partitioning and transmuting, space disposal, ice sheets, deep geological formations, salt formations, clays, hard rock, the ocean, the ocean bottom, and sub-seabed areas are all ways to dispose of materials. The geologically acceptable site is the waste shape that may operate as a containment barrier, which can be strong enough. How long the trash will stay there, and how to use multiple barriers are important design concerns. The ability of the waste form to absorb mobilized species is essential for containment. Because the world needs more energy, nuclear power remains a prominent option, making waste management even more crucial [13]. Radioactive waste must be stored in geological formations that will not change for thousands of years. Countries without sufficient capacity to store waste fuel are sending it to foreign suppliers for reprocessing or developing central storage facilities. Too many low- and intermediate-level trash increases environmental contamination. The dumping of trash into the Irish Sea has been linked to higher radiation levels. Radioactive waste must be carefully handled during its production and disposal because of its long-term risks. Permanent isolation is largely accepted for high-level waste, whereas low- and intermediate-level waste treatment remains difficult. Normal norms cannot govern radioactive waste because it decays naturally and cannot be removed or modified [14].

Nuke Proliferation

The expansion of nuclear weapons is worried about as political and economic instability rises worldwide. The 1968 Nuclear Non-proliferation Treaty (NPT) lists the US, Russia, Great Britain, France, and China as nuclear powers. India, Pakistan, and Israel have undeclared nuclear weapons. NPT defines proliferation as countries without nuclear weapons making or acquiring them [15].

UK civil nuclear power stations have no off-site consequences, and safety measures are exhausted. Modern reactor designs may further reduce accidents by applying passive safety mechanisms [12]. Such concepts include large containment buildings that can withstand commercial airline attacks. When plants are attacked or damaged, safe shutdowns are likely; however, terrorists may exploit their weaknesses. It is difficult to transform reactor fuel into weapons-grade materials, but it can be used in a “dirty bomb”. Opening large nuclear canisters without adequate instruments exposes opponents to radiation. The UK will not use civilian nuclear resources for military purposes under the Non-Proliferation Treaty and Euratom Treaty. If one leaves these treaties, other nations will be suspicious and act. Despite terrorist groups breaking national and international laws, independent safety procedures in fuel manufacturing, reprocessing, and power plants have been implemented.

The nuclear fission energy of different countries can increase or decrease. Small or tiny reactors may grow, whereas large reactors shrink. The problems include fuel shortages, sophisticated reactors, and new rules. Industrialization followed the discovery of the nucleus, Einstein, and Fermi. Inefficiency, miscommunication, and politics have led to new issues. Unsolved scientific issues fuel anti-nuclear sentiment and jeopardize nuclear technology [1]. Deeply studied discoveries remain elusive.

CASE STUDIES OF NUCLEAR EVENTS

Nuclear accident case studies have demonstrated the dangers of nuclear energy and the effectiveness of safety mechanisms. Because of its radioactive dispersion, the late 1980s Chernobyl nuclear disaster in Ukraine is considered the worst. The operators began testing one of the four reactors of the plant. The intense power surge ruptured the core vessel and destroyed its roof. Before the core could be secured, the radioactive material spilled, and a large fire contaminated the area. Chernobyl was first classified as a "Level Four" catastrophe on the International Nuclear Event Scale because the Soviet Union hid it. Catastrophe was later classified as "Level Seven"—the highest. Media coverage has shaped public opinion on nuclear power [12].

Japan experienced a three-fission-reactor meltdown a year later. The power outage induced by devastating earthquakes and tsunamis disabled safety devices, causing an uncontrolled fission reaction that released massive amounts of radioactive material. Hydrogen explosions and low water levels melted reactor cores. A decades-long evacuation and no-fishing zone covers 70 miles of the site.

The Three Mile Island nuclear disaster in Pennsylvania was caused by mechanical failure, human error, and design uncertainties. Two nuclear power stations were installed. A loss-of-coolant accident occurred under the control conditions. After several hours, the reactor core was burned. Helping made things worse, and half of the molten fuel fell through the reactor vessel's bottom into the concrete underneath the power station. The tragedy proved that safety mechanisms and nuclear manager training were flawed, even though the surviving core was saved and stabilized.

The Chernobyl Disaster

Chernobyl was the first and worst nuclear accident. The safety systems were intentionally turned off, and the output of the Reaktor Bolshoy Moshchnosti Kanalnyy (RBMK) reactor was reduced to 25% during a planned shutdown on April 26, 1986. Although the reactor was unstable at less than 22% power, operators did not adjust the controls. The power fluctuated during the test; therefore, the control rods were removed to compensate for xenon toxicity. Only 6–8 rods remained instead of the required 30. Numerous automatic trip circuits were switched off to prevent premature reactor shutdown.

The turbine was tripped to simulate a power outage and to stop the main cooling water pumps. This resulted in a 100-fold power spike and rapid boiling of water. The fuel rods broke, the coolant water turned into steam, and reactor pressures blasted off the biological barrier because of the rapid temperature rise. The pressure tubes broke, resulting in a hot core. Several radioactive materials have been released. Three days after dumping contaminated water and debris into the reactor hall, airborne particulates swept across Western Europe. Radiation exposure resulted in the death of 31 nuclear and first responders. In 2005, the International Atomic Energy Agency (IAEA) predicted 4,000 deaths due to radiation-related illnesses.

The accident occurred because of several safety violations. Although the conditions were unstable, the operators felt pressured to finish the experiment because terminating it would have taken a year. The Chernobyl disaster has changed nuclear safety worldwide. When the accident occurred, the U.S. had mainly stopped developing nuclear facilities. The remaining reactors, including Watts Bar, were completed in 1996. The U.S. generates 20% of its electricity from 104 reactors. Even though most nuclear decay produces ionizing radiation, which is hazardous only when it touches live tissues, public fear of radiation still plagues nuclear energy.

Accident at Fukushima

The Fukushima Daiichi Incident occurred on March 11, 2011, after a massive earthquake and tsunami unparalleled in over 1200 years. Accidents that occurred at Fukushima Daiichi Nuclear Power Station (NPS) Units 1–4. Units 1–3 ran, but unit 4 was repaired. A tsunami that destroyed the power supplies within and outside the structure shut off the cooling systems, causing a catastrophe. Spent fuels release heat for days after shutdown; therefore, they require constant cooling. The cladding reaction produces hydrogen and melted ceramic fuels, which release radioactive materials as the fuel temperature increases rapidly without cooling. The hydrogen buildup destroyed Units 1, 3, and 4 and released radioactive gases. Important Heating, Ventilation, and Air Conditioning (HVAC), lighting, telephony, and instrumentation systems were lost. After some cooling systems worked without AC power, power was lost. Firefighters and circulation-cooling systems were added to the water. Short-term radiological releases of 3 mSv/h could have affected crops and dairy products; however, areas within 50 km did not need to be evacuated. Iodine pills were proposed, but experts did not think they were needed. The Japanese government later reported that all units were stable and that radioactive discharge had nearly stopped. Political and safety reviews in Japan and the world have followed this trend. In reaction, Germany and Italy were phasing out nuclear power. Future safety efforts should include reassessing earthquake and tsunami threats, building placement, risk tolerance, risk limitations, and passive safety devices. With an ongoing debate about the role, safety, and future of nuclear power, societal reactions were less severe than after Chernobyl and Three Mile Island [16, 17, 2].

Accident at Three Mile Island

A minor equipment issue at the Three Mile Island reactor became a major issue in March 1979 owing to operator errors. This partially melted the core of the reactor. Radiation infiltrated the neighboring structural areas when the shattered core was placed in the cooling water. A small amount of radioactive steam leaked into the air. After the disaster, regulatory and industry precautions were criticized and studied, changing the U.S. nuclear power regulations. This occurrence was remembered as a sign of nuclear risk and may have ended the US reactor construction.

PUBLIC PERCEPTIONS ON NUCLEAR ENERGY

Although nuclear power is safe, many are still mistrustful. The Canadian Nuclear Safety Commission reports no nuclear incidents that have harmed people or the environment during 40 years of commercial operation. The nuclear fuel cycle causes fewer accidents and deaths than other global electricity sources. Nuclear power has saved millions of lives and reduced carbon dioxide emissions by 64 gigatonnes, thus benefiting people and the environment. Still, 55% of Canadians thought that nuclear energy was "very" or "extremely" risky in 2012. A 2011 poll in 24 nations revealed 62% opposed nuclear energy. Low public trust in the government and business, terrible media coverage, and memories of Chernobyl and Fukushima exacerbate these concerns about nuclear weapons, waste management, and proliferation. These factors have led many people to assume that nuclear power is dangerous, despite being safe and helpful for the environment [11]. The enormous number of accidents at Three Mile Island and Chernobyl have made people even more scared. According to research, quantitative and qualitative factors such as anxiety and fear alter how people perceive danger. People consider systems with low probability but high consequence calamities riskier than those with higher probability but lower consequence disasters. Regulators, industrial stakeholders, and environmentalists influence public opinion. Education and trust can resolve misunderstandings [18].

Polls, Surveys

Burgin [19] assessed public opinion on license renewals and future nuclear facilities by surveying Delaware business executives and local politicians near Salem and Hope Creek Nuclear Generating Stations. The design measures community support for these activities to gauge society's acceptance or apprehension.

Public support was consistent from the mid-1980s to the mid-1990s, with a brief rise during the Gulf War. The support for renewing licenses rose from 79% to 85%, the desire to keep development options open rose from 60% to 74%, and the percentage of people who desired new nuclear plants rose from 42% to 63%. By 2001, 42% supported additional buildings (up from 22% in 1991) and 51% supported larger development (up from 41% a decade earlier). On September 11, 2001, the attacks further altered opinions. In October 2001, the Edison Electric Institute and the Nuclear Energy Institute found that 65% of Americans supported nuclear power, 66% thought that existing facilities were safe, and 59%

favored building more units. This was a slight decrease compared to the March survey. Few companies in the business have conducted local opinion polls; thus, most of the data is private and cannot be analyzed.

Influence of Media

Numerous public opinion surveys have shown the benefits and risks of nuclear technology conflicts [11]. Nuclear energy is vital; however, it still affects cultural life in many regions. These contradictory ideas affect stakeholder debates, national risk credit perceptions, and the expanding gap between professional and lay risk evaluations. When public support for technology is significantly influenced by perceptions of danger, societal concerns must be addressed to achieve acceptance.

The credibility of nuclear energy depends on facts, data, the media, and political debates regarding potential risks. Studies have shown that non-experts rely on the media for knowledge. Although people actively develop their judgement frameworks, pre-existing attitudes and ideas impact their interpretation and remembering information. The media shape people's views on nuclear energy. Its place in the community and national media shapes debates and public opinion.

Media portrayals alter risk perceptions, not just nuclear ones. Pollution, food, and job dangers have been discussed in various media sources. Mass media do this by dividing stories into episodes or topics. Both frames raise awareness about various issues and their effects. Episodic framing promotes "blame the victim" and a lack of context for political interpretations by emphasizing the specific occurrence rather than the larger problem. However, the conceptual framework creates a wider picture and enables the formation of judgements about societal duty. Research has shown that framing genres vary by media and audience. Press media use themes, whereas traditional broadcast media use episodes.

NUCLEAR ENERGY RULES

The worldwide nuclear sector relies on legislative regulations that all organizations must comply with. This extensive regulatory framework encompasses garbage management and disposal. The regulatory authority implements rules and works with the public and government regarding technical difficulties. To be fair and professional, the regulatory authority must be independent of the government. Regulators also oversee the nuclear accident plans. Regulators authorize all nuclear materials and processes. Building and operating nuclear facilities; processing radioactive waste; security, transport, and safety are typical. The applicant must perform an environmental impact assessment because license holders must follow the release rules. All reports and evaluations must be approved by the regulatory agencies before use. Regular inspections assess a company's emergency readiness. The building and operation of a nuclear power plant require several regulations. National and international "best practice" guidelines from almost 60 years ago and the new European Directive on Nuclear Safety have provided these rules. Regulators must be trained and developed to monitor regulatory applications and actions effectively [2]. Policymakers perceive nuclear energy as essential to their energy development strategy to meet demand, improve security, and mitigate climate change. Nuclear and renewables will receive four-fifths of their low-carbon investments between now and 2060, according to the International Energy Agency Mid-Century Plan. It also predicts a 10%–16% increase in nuclear power generation. According to the World Nuclear Association [3], the estimated increase in yearly new builds indicates that global capacity will not be exceeded until the mid-2020s. Based on Fukushima's net capacity.

Treaties Between Nations

Global nuclear energy control requires international treaties. The 1957 EURATOM Treaty promoted peaceful nuclear energy use in the European Atomic Energy Community. It is constantly changing, but it was the most essential aspect of EU nuclear law decades later [20]. EU pressure to control the nuclear industry has persisted. Nuclear non-proliferation is another EU security and defense priority. The fact that member states have different nuclear weapons policies makes it impossible to reach a consensus.

Thus, the Nuclear Non-Proliferation Treaty and the EURATOM Treaty balance the Union's nuclear weapons halting approach.

National Policies

EU member states have different nuclear energy ideas, making it difficult to create a uniform policy. Despite many changes since the 1950s, when nuclear power was considered the "energy source of the future," policymakers and the public still worry about risks. Several nuclear energy issues need to be resolved. There are concerns about dangerous radioactive emissions, long-lived nuclear waste, energy supply vulnerability to proliferation, sabotage, terrorism, and international relations militarization. EU lawmakers are cautious and do not discuss nuclear energy [21]. This limits energy policy collaboration and prevents a united EU nuclear energy policy. Instead, the member states have distinct policies. Some countries are building new plants or considering them, while others are prolonging the lifetimes of existing facilities and storing waste for a long period, and others are planning a gradual nuclear power shutdown.

FUTURE NUCLEAR ENERGY: WHAT HAPPENS?

After Chernobyl, people looked for ways to make nuclear reactors safer beyond design adjustments. A few years later, nuclear energy promotion and contract reactivation accelerated. Understanding the factors that shape technology is crucial.

Nuclear fission energy is at a crossroads; some countries may cut back or cease programs, while others may expand. Therefore, microreactors may become increasingly popular in the future. The future of sodium-cooled fast reactors, various novel technologies, and thorium as fuel is uncertain. Nuclear technology began with an understanding of atoms and how they work, but it has been a long and difficult route to produce large amounts of electricity [1]. There is no solution at the end of the cycle, fuel systems are weak, and the proposed designs are becoming more intricate, although standards have not changed since the 1970s. If large reactors function, tiny microreactors may be ready. Installation of a new safety barrier is important. Nuclear energy has advanced in less than a century; however, unresolved scientific and technical challenges and social misunderstandings threaten its future. Large reactors may go, and basic research is declining. Lack of understanding increases prices, wait times, and cancellations, unintentionally strengthening anti-nuclear sentiments.

Nuclear technology underlies the global society; therefore, the Nordic-Baltic perspective underlines its permanent impact. Maintaining nuclear proficiency is strategic given climate change. The threat of nuclear weapons remains in the global infrastructure and geopolitical frameworks, even though people no longer read about them. Energy transition demands vision and international cooperation to address security and sustainable development [22].

Enhancements in Technology

Key points: Nuclear fission energy can rise or fall in different countries. Microreactors may become more common as larger reactors disappear. Using thorium fuel in sodium fast and innovative reactors is uncertain. A brief history explains how humankind used nuclear energy to create power after discovering the atomic nucleus. Problems remain in nuclear waste management, reactor safety, regulatory frameworks, and small microreactors. These reactors require massive infrastructure to survive. Therefore, a new technology safety barrier is required to address these issues.

The nuclear era occurred during a time of great global change and lasted a century, with some changes occurring in one generation. In less than a century, several breakthroughs have enabled nuclear power. However, its technological basis is fragile and susceptible to social change. Although nuclear fission is still possible, technology, economy, law, and politics can eliminate large reactors. Unresolved technical concerns, escalating prices, delays, and project cancellations exacerbate these uncertainties, favoring anti-nuclear parties [1].

Nuclear Practices that Last

Sustainability is the key to integrating nuclear energy into sustainable development. The rapid development of nuclear power threatens its sustainability. Thus, policies have focused on withdrawal and mitigation. Fast reactor systems, improved fuel cycles, waste management, and safety improvements are environmentally friendly technologies. Sustainability requires low-cost technology, strong safety requirements, better waste management, and decent worker relationships. Strong community opposition to these duties delays progress. Sustainability promises job growth, expansion, and quality of life, but requires closer inspection of company and enterprise policies and practices. During a period of climate change and resource shortage, nuclear sustainability affects the evaluation of nuclear contributions [8].

COMPARISON TO OTHER ENERGIES

Unlike other sources, nuclear energy produces power. It produces radioactive chemicals from uranium and thorium fuels, fission, nuclear core activation, and non-working fuel elements. Energy safety and regulation must be higher than those of other types. This results in longer building hours and higher costs. However, nuclear reactors track loads well, and operational delays that require expensive grid purchases are rare [3]. Renewable energy methods have little effect on resource endowment. We expect fossil fuels, uranium, and thorium to be abundant by 2050. Thus, energy supplies are unlikely to cause global conflict or dependence [8]. Large renewable energy projects can influence local temperature and humidity; therefore, their location can reduce their environmental impact [2]. The availability and use of fossil fuels affect global stability. Nuclear fuel storage has provided energy for hundreds of years, but fossil fuels are limited.

The perceived value of clean air affects how well new nuclear facilities are compared with others. Renewable technologies, which are typically alternative technologies, rarely affect large-scale power plants. Distributed renewable energy can meet electricity needs and extend its availability in developing nations. Renewable energy generates power from multiple sources and reduces environmental effects.

The economics of nuclear power allow countries with large uranium stockpiles and enriched fuel to compete in the energy market. It is difficult to compare countries. Nuclear power costs, excluding capital costs, are stable. However, they can transform fossil fuels and non-mechanical renewables. Fuel prices, availability, efficiency, demand, and exchange rate changes are complicating comparisons. Access to full-life-cycle evaluations is rare.

Energy from Renewable Sources

Renewable energy sources, including wind, solar, tidal, geothermal, and biofuel, do not require ongoing replenishment. They lose their stored potential as they are used. Renewable energy can be expensive for people, businesses, and the environment. These resources vary according to location, from abundance to scarcity. In addition, renewable energy sources can fail. Solar power is unavailable at night and is weaker on overcast days. Winds may die down, and river flows may alter seasonally. Renewable energy providers may need fossil fuel plants or large storage systems to address these issues. Therefore, renewable energy sources are generally preferable as secondary sources to primary sources [2].

Visions, solid plans, and youth involvement are required to move beyond oil and gas. Thinking ahead and cooperating with experts from other sectors is necessary for sustainable development, which addresses the present needs without harming future generations. Even though many want to eliminate nuclear weapons, nuclear technology is vital to civilization, and understanding how nuclear energy influences society is crucial. Ten years ago, Freeman Dyson stated that the nuclear weapons inventory had grown smaller, but the threat remains. Peace and security depend on nuclear technology, and Cold War nuclear programs still shape the world [22].

The Fossil Fuels

The industrial revolution has replaced organic fertilizers with rock phosphate from prehistoric sea animal bones. This harsh phosphate supply has helped mine mineral resources for 150 years and is one reason why the human population has increased swiftly. Most of these minerals are now fertilizers that feed the growing population. Managing the increasing global population is crucial. Most of the world's choices are difficult.

Approximately 80% of the energy originates from fossil fuels. However, after a century of seemingly endless expansion and rapid technological progress in all sections of the supply chain, crude oil extraction, processing, and production essentially stopped. Revolutionary reservoir monitoring and extraction have yielded varying results. It should be noted that petroleum fluid only forms under certain geological conditions and takes a long time. Updated petroleum system models include communication networks that promote fluid accumulation in production areas. Subsequent alterations show that the deposits have a repeating history. The tertiary and quaternary infill phases require petroleum fluids later than expected. Identifying and studying this phenomenon shows a significant decline in reserves in several major fields worldwide [23, 24]. The running out of many old fields cannot be made up for by the new fields being produced. Transportation and logistics have worsened this issue. Dealing with the fossil fuel crisis has become more urgent as discourse continues.

CONCLUSION

A well-balanced debate continues over whether nuclear energy is safe, reliable, or a terrifying menace to meet global energy needs. Nuclear energy does not create climate change, which is excellent. It uses much less land than low-carbon alternatives do. It can be used to heat, produce chemicals, and generate energy. Global research and development initiatives have been improving, and many countries have robust nuclear disaster prevention laws. Despite these benefits, nuclear energy remains a concern. The Chernobyl, Fukushima, and Three Mile Island nuclear accidents have harmed society. Nuclear proliferation and the financial and safety challenges associated with long-term nuclear waste storage remain.

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