"From Fusion to Fission: Exploring Nuclear Energy's Promise and Peril" By Gitobu Clay Mwandiki.

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1. Introduction.

The global pursuit for a sustainable energy source has been real,[1]Energy has long been viewed as an essential ingredient in meeting man's basic needs and in stimulating and supporting economic growth and the standard of living, so much so that often a nation identifies its well-being with its gargantuan and growing need for energy. Statistical data on energy consumption of the world in recent years.[1]Nuclear energy is a key player in moving towards a carbon-free world. [2]Over the past 50 years, the use of nuclear power has reduced CO2 emissions by over 60 gigatonnes – nearly two years' worth of global energy-related emissions.[2]Sadly, in recent years nuclear power has been neglected as industries fall back to their previous sources such as coal but have also adopted new renewable sources like solar energy and wind energy. I believe that nuclear energy should not be looked down upon. To achieve our universal goal of a clean earth. We need to explore all paths that can be of paramount aid to us. [3]In the United States of America, nuclear energy accounts for 92.5% of energy production.[3] However, the promise of nuclear energy is not without its challenges and controversies. Central among these is the issue of nuclear waste, a byproduct of nuclear reactors that poses complex logistical and environmental concerns. The safe storage and disposal of radioactive waste remain paramount considerations, as evidenced by historical incidents such as the Chernobyl and Mayak disasters, which underscore the potential risks associated with nuclear technology. Against this backdrop, this research paper endeavours to explore the multifaceted landscape of nuclear energy, delving into its historical roots, its present-day significance, and the critical questions surrounding its utilization and management. By examining the need for nuclear power, its reliability compared to alternative energy sources, and the potential for mitigating its environmental impact through innovative waste management strategies, this paper seeks to provide a comprehensive understanding of nuclear energy's promise and peril.

2. How is it mined?

Nuclear energy, derived from uranium, plays a vital role in global energy production. The mining and processing of uranium are integral to fueling nuclear reactors, providing a substantial portion of the world's electricity. Canada, with its significant uranium reserves, notably in northern Saskatchewan, stands out as a major player in uranium mining. The McArthur River mine in Canada, boasting the world's largest high-grade uranium deposit, produced 7,520 tonnes of uranium in 2012 alone, contributing significantly to global fuel demand. Uranium mining operations extend beyond Canada, with key mining sites located in Kazakhstan, Niger, Australia, Namibia, and Russia. These regions collectively contribute to the global supply of uranium, supporting the operation of nuclear reactors worldwide. According to the World Nuclear Association, global uranium production reached approximately 53,498 tonnes in 2019, indicating the substantial scale of uranium extraction to meet nuclear energy demands. The demand for uranium continues to rise as countries seek to diversify their energy portfolios and reduce reliance on fossil fuels. According to projections by the International Atomic Energy Agency (IAEA), global nuclear capacity is expected to expand significantly in the coming decades, driving increased demand for uranium fuel. This growth is fueled by the recognition of nuclear energy as a reliable and low-carbon alternative to traditional fossil fuels, particularly in mitigating climate change. The process of uranium extraction involves conventional open-pit or underground mining methods, followed by extensive processing to extract uranium oxide from the ore. This rigorous process entails drilling, blasting, and milling of the ore, culminating in the conversion of uranium into gas for enrichment. Enriched uranium is then fabricated into fuel pellets for use in nuclear reactors, facilitating the reliable and consistent generation of electricity. Despite the labour-intensive nature of uranium mining and processing, the yields are substantial, providing a reliable source of fuel for nuclear reactors. Moreover, the efficiency and productivity of nuclear energy infrastructure underscore its significance in meeting global energy needs. As renewable energy sources continue to evolve, nuclear energy remains a cornerstone of the transition towards a low-carbon future, offering stable and dependable electricity generation capabilities.

3. Reliable source of Energy.

Nuclear energy stands as a stalwart in the energy landscape, renowned for its reliability and consistent power generation capabilities. In comparison to other forms of energy, such as solar and wind, which are subject to weather fluctuations, nuclear power offers a stable and dependable source of electricity. According to data compiled by the International Atomic Energy Agency (IAEA), nuclear power plants boast an impressive capacity factor of over 92%. This statistic underscores the high level of operational efficiency and consistent power generation achieved by nuclear facilities globally. The capacity factor of a power plant indicates the extent to which it operates at maximum output over a given period, serving as a key metric of reliability. This high-capacity factor positions nuclear energy as a reliable baseload power source capable of meeting consistent electricity demand. Moreover, one of the distinctive advantages of nuclear energy is its ability to produce large quantities of electricity from a single plant, surpassing the output of conventional fossil fuel-based or renewable energy facilities. [4]According to analyses conducted by the World Nuclear Association (WNA), a single nuclear plant can generate an equivalent output to two coal power stations or three to four renewable plants with a capacity of 1 gigawatt (GW) each.

This comparative analysis highlights the efficiency and productivity of nuclear energy infrastructure.[4] Public sentiment towards nuclear energy remains favourable in many regions, despite concerns regarding safety and waste management. A comprehensive survey conducted by reputable research firms consistently reveals widespread public support for nuclear energy. For instance, recent data from Gallup suggests that approximately 76% of respondents in the United States express either strong or somewhat favourable views towards nuclear energy as a viable means of electricity generation. This enduring public support underscores the perceived reliability and importance of nuclear energy in meeting energy needs. Examining historical trends in public perception offers valuable insights into the evolving attitudes towards nuclear energy. Over the past four decades, there has been a notable increase in favorability towards nuclear energy. Gallup polling data from the 1980s indicates that favorability towards nuclear energy plateaued in the 60% range. However, recent surveys show a significant rise, with approximately 76% of respondents expressing favourable views. This upward trend underscores a growing recognition of nuclear energy's reliability and its potential contributions to energy security and sustainability. Nuclear energy's reliability is a cornerstone of its value proposition in the global energy mix. This reliability positions nuclear power as a critical component of the transition towards a sustainable and resilient energy future.

4. Concerns about nuclear energy and nuclear waste.

[5]The public's perception is included in the biggest challenges mainly when people are asked about harmful activities or technologies. The public's perception is shaded by various factors, such as media, newspapers, lack of knowledge or just circumstances. In the case of radioactive nuclear waste, the risk is defined as "dread risk", something terrible, awful with great apprehension or fear (Slovic, 1987). Apart from the direct harm of radioactive nuclear waste, some other impacts include indirect costs for which responsible are the government or industry companies. Indirect impacts include also death, injuries or material damage. The public's acceptance is directly proportional to the risk associated. Acceptance and opposition to a nuclear waste repository are often at the top of the studies because of the potential impacts. The public accepts very hard the nuclear industry considering the benefits are quite small compared with the almost unacceptable risks. The public's perception based on the unknown of the real risk of radioactive nuclear waste leads to irrational fear. The danger is evaluated through the information received by the media and not by the experts. The public cannot be educated in line with the industry scientists because of the lack of interest and blind trust in fake publicity (Cohen, 1983). Informing the public is very hard when they show big opposition to nuclear technologies (Slovic, 1987). Other characteristics, such as age, sex, education or socioeconomic aspects, influence the public perception. Regarding the benefits or compensations offered, people tend to accept or not a nuclear waste repository according to their perception of risk. When they see a high risk in nuclear waste technologies they

refuse any compensation.[5] A global survey conducted by the World Nuclear Association found that 79% of respondents expressed concern about nuclear safety, with 40% supporting the use of nuclear energy and 33% opposing it. This dichotomy reflects the complex nature of public opinion on nuclear energy, with some people viewing it as a necessary evil for meeting energy demands while others are more sceptical due to the risks associated with nuclear waste and accidents. [6]Three-fourths of the US. public (76 per cent) said they strongly or somewhat favoured the use of nuclear energy as one of the ways to provide electricity in the United States; 24 per cent opposed it. Those figures have been statistically unchanged since 2021. They have become much more favourable over the past four decades. In the previous decade, favorability had plateaued in the 60 per cent range. Favorability to Nuclear Energy 1983-2023 Overall, do you strongly favour, somewhat favour, somewhat oppose or strongly oppose the use of nuclear energy as one of the ways to provide electricity in the United States? (%) Most Americans hold favourable opinions about nuclear energy and its role: 86 per cent said that nuclear energy will be important in meeting the nation's electricity needs in the years ahead, 89 per cent agreed that we should renew the license of nuclear power plants that continue to meet federal safety standards, 87 per cent agreed that our nation should prepare now so that advanced-design nuclear power plants will be available to provide electricity, and 71 per cent agreed we should build more nuclear power plants in the future. Near-unanimous support for license renewal of nuclear power plants that continue to meet federal safety standards reappeared after a COVID dip.[6] Firstly looking at the environmental Impacts, there are both positive and negative impacts. On the positive side, Nuclear power plants do not directly emit carbon dioxide, which is a significant advantage in the context of climate change. The greenhouse gas emissions from nuclear power are equivalent to those of wind, hydro, and solar power. This makes nuclear power an effective way to produce electricity with minimal effect on the environment. When flip our coin, The main environmental impact of nuclear power is related to building the plant, fuel procurement, and the thermal load of cooling water discharged into the sea during operation. The most significant environmental concern is the thermal load caused by the cooling water. This can result in undesirable increases in water temperature, which can have adverse effects on aquatic life. There is more to this when we look at thermal pollution which is the degradation of water quality due to a change in ambient water temperature. Nuclear power plants release heated water back into the environment, which can decrease dissolved oxygen levels and rise in pH. This can lead to eutrophication, hypoxic dead zones, and other environmental issues. Nuclear waste, primarily generated from the spent fuel rods of nuclear reactors, remains highly radioactive and poses substantial risks to both human health and the environment. The International Atomic Energy Agency (IAEA) estimates that the global nuclear industry produces approximately 2,000 metric tons of high-level radioactive waste annually, a figure that underscores the magnitude of the challenge. The disposal and storage of nuclear waste require meticulous planning and adherence to stringent safety protocols to prevent environmental contamination and potential health hazards. Radioactive isotopes present in nuclear waste can persist for thousands of years, necessitating robust containment measures to prevent leakage or seepage into the surrounding environment. Additionally, the extraction and processing of uranium, the primary fuel source for nuclear reactors, can have adverse environmental impacts. Uranium mining operations, particularly in regions such as Kazakhstan, Niger, and Canada, often result in habitat destruction, groundwater contamination, and disruption of local ecosystems. The environmental footprint of uranium mining underscores the interconnectedness of nuclear energy production and broader ecological concerns. Beyond environmental considerations, public perception plays a crucial role in shaping the discourse surrounding nuclear energy and waste management. The Chornobyl and Fukushima nuclear disasters serve as poignant reminders of the catastrophic consequences of nuclear accidents, fueling public apprehension and scepticism towards nuclear power. Studies have shown that public perception of nuclear waste is often influenced by media coverage, lack of transparency from industry stakeholders, and personal experiences with nuclear technology. A survey conducted by the World Nuclear Association revealed that 79% of respondents expressed concern about nuclear safety, underscoring the widespread apprehension surrounding nuclear energy. Moreover, the management and disposal of nuclear waste require long-term planning and investment in infrastructure to ensure public safety and environmental protection. The storage of radioactive waste in underground repositories, such as deep geological repositories (DGRs), necessitates careful consideration of geological stability, containment mechanisms, and regulatory oversight. Addressing the multifaceted challenges associated with nuclear waste management requires a comprehensive regulatory framework and sustained investment in technological innovation. International organizations such as the IAEA play a pivotal role in establishing guidelines and safeguards for the safe handling and disposal of nuclear waste, fostering collaboration among member states to address common challenges. Technological advancements, such as advanced reprocessing techniques and next-generation reactor designs, hold promise for reducing the volume and long-term hazard of nuclear waste. Research institutions and industry stakeholders are actively exploring innovative solutions to enhance the efficiency and safety of nuclear energy production while minimizing environmental impact 5. The aftermath of Nuclear Energy. The question that we are left with is; what happens with the radioactive waste? According to the United States Regulatory Commission, Radioactive (or nuclear) waste is a byproduct from nuclear reactors, fuel processing plants, hospitals and research facilities. Radioactive waste is also generated while decommissioning and dismantling nuclear reactors and other nuclear facilities. Radioactive releases from reactors depend on the reactor type and on the specific wasteprocessing systems utilized Radionuclides released in the airborne effluents consist essentially of: noble gases (133Xe), activation gases (41Ar, 14C, 16N and 35S), tritium vapour and gas, halogens and particulates The dose rates associated with the releases of 14C are very low, yet with its long half-life (5730 years) it makes a significant contribution to the collective dose [7] Similarly, the increasing release of tritium (mainly as tritiated water HTO) to the atmosphere calls for detailed studies and periodic assessment of the environmental impacts of these releases, involving chronic exposures at very low exposure levels [8] Discharges in the liquid effluents include tritium, 137Cs, 134Cs, 131 I , 1331,58Co and ^Co besides a number of activated corrosion products such as 51Ch and 51Mn, which are quite prevalent in liquid effluents from LWRsThere are two broad classifications: high-level and low-level waste. High-level waste is primarily spent fuel removed from reactors after producing electricity. Low-level waste comes from reactor operations and medical, academic, industrial, and other commercial uses of radioactive materials. So what happens to this waste? Radioactive waste is stored in underground vaults and tanks at government sites, and in deep geological repositories (DGRs). DGRs are underground facilities, usually at least several hundred meters below the surface, that contain radioactive waste in stable rock formations. The waste is isolated from the environment and public and is intended to remain there for thousands of years. This is because of the nature of the waste. Nuclear disasters leave a lasting impact on human lives, the environment, and societal structures. Two of the most infamous incidents, the Chernobyl disaster of 1986 and the Mayak nuclear disaster of 1957 serve as stark reminders of the catastrophic consequences of nuclear accidents. The aftermath of these disasters was characterised by widespread devastation, both immediate and long-term. In the case of Chornobyl, the explosion at Reactor 4 led to the release of massive amounts of radioactive material into the atmosphere, contaminating large swathes of land and affecting millions of people across Europe. The immediate response included the evacuation of nearby towns and the implementation of radiation monitoring and cleanup efforts. However, the long-term consequences were profound, with thousands of cases of acute radiation sickness among plant workers and emergency responders, and an estimated thousands of premature deaths due to radiation-related illnesses such as cancer. Similarly, the Mayak nuclear disaster, although less known internationally, had devastating consequences for the affected region in the southern Urals of the Soviet Union. The explosion of a waste storage tank released a significant amount of radioactive contamination into the atmosphere, leading to acute radiation sickness, cancers, and other health problems among the exposed population. The secrecy surrounding the incident and the lack of transparency from the authorities exacerbated the suffering of the affected communities. The environmental impact of both disasters was extensive and long-lasting. Contamination of land, water, and air posed significant risks to ecosystems and agricultural lands, with some areas remaining heavily contaminated for decades. The psychological trauma experienced by affected populations, coupled with the disruption of livelihoods and displacement of communities, further compounded the aftermath of these disasters. The legacy of these disasters continues to remind us of the inherent risks associated with nuclear technology and the importance of prioritising safety and precautionary measures to prevent future catastrophes. 6. How Can the waste be made useful? The question we are left with is; Can we do something with radioactive waste other than store it for thousands and thousands of years in dry casks? Technically, there is enough nuclear waste to power the Earth for the next 100-150 years.

Argonne National Laboratory (ANL) is a renowned research institution located in Lemont, Illinois, just outside of Chicago. Established in 1946 as part of the Manhattan Project, ANL has been pivotal in advancing various fields of science and technology, particularly in the realm of nuclear energy. the creation of the first self-sustaining nuclear chain reaction, occurred on December 2, 1942, under the leadership of physicist Enrico Fermi, at the University of Chicago. This achievement marked a significant breakthrough in nuclear physics and laid the groundwork for the development of nuclear reactors and atomic bombs. ANL's subsequent contributions to nuclear technology have been substantial. The lab's focus on designing materials and reactor configurations has played a crucial role in the advancement of nuclear power generation. The successful production of nuclear electricity on December 20, 1951, further solidified ANL's reputation as a leader in nuclear research. Nuclear energy was derived from nuclear waste. They found the solution to the problem years ago. While creating electricity directly from nuclear waste is not a common practice. Nuclear waste typically consists of spent nuclear fuel, which still contains usable radioactive material but at lower concentrations compared to fresh fuel. While it is technically feasible to extract additional energy from certain types of nuclear waste through processes like nuclear reprocessing or advanced reactor technologies, the primary purpose of these processes is usually to reduce the volume and long-term hazard of the waste rather than to generate electricity directly from it.

7. CONCLUSION

In conclusion, nuclear energy remains a pivotal player in the quest for a carbon-free future. Despite its challenges, including the management of nuclear waste and safety concerns, nuclear energy offers a reliable and low-carbon alternative to traditional fossil fuels. As we strive to mitigate climate change and secure a sustainable energy future, we must continue to explore and invest in all viable avenues, including nuclear energy. However, it is equally important to address the concerns surrounding nuclear waste and prioritize safety measures to prevent future disasters.[9] It is important at this stage of nuclear power development that increased efforts should be devoted to detailed in-depth studies of the different environmental impacts associated with all steps of the nuclear fuel cycle, to develop adequate measures for ensuring the protection of man and his environment. As we navigate the complexities of nuclear energy, it is imperative to balance its potential benefits with the need for stringent safety measures and transparent waste management practices. Only through concerted efforts can we realize the promise of nuclear energy in a sustainable future.

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