



Environmental impact of nuclear activities in Ghana: lessons on effective waste management systems

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Abstract

Nuclear activities offer substantial advantages to Ghana. These benefits encompass energy security and less greenhouse gas emissions. Nonetheless, the adoption of nuclear activities and its nuclear energy requires strict environmental protection measures and effective waste management systems. This paper examines the environmental impact of nuclear activities in Ghana and underscores the need for robust waste management by providing an outline of the Ghanaian nuclear energy environment and the primary national legislation governing nuclear activities and waste management of by-products of nuclear activities. It discusses the Nuclear Regulatory Authority Act, 2015 (Act 895), together with other legal frameworks, including International Laws and Regulations or legislations, conventions, pacts, and treaties that govern nuclear activities and effective waste management, for which Ghana is a signatory. This paper also analyses the nuclear cycle and the effects of the nuclear cycle on the environment, highlighting the importance of peaceful and safe use of nuclear energy and effective waste management on the environment.

The paper draws lessons from the accidents resulting from nuclear activities in other nations, including the Chernobyl and Fukushima accidents. It further discusses successful and unsuccessful waste management programs which can guide Ghana's environmental protection template. It reviews international best practices and standards and their application in Ghana. Challenges in enforcing these practices are addressed, with suggested mitigating measures.

The writer makes recommendations on stronger regulatory control, the creation of a national nuclear waste management strategy, the promotion of international collaboration, and research and development funding. The conclusion underlines the significance of efficient waste management for Ghana's sustainable nuclear power development and advocates for a responsible long-term strategy.

Keywords: Nuclear energy, waste management, national and international laws and regulations or legislation on nuclear activities and waste management

Introduction

In search of sustainable and reliable sources of energy for the production of electricity and a reduced general damage to the environment, a lot of countries around the world have invested in nuclear energy ^[1]. From as far back as the 1950's, policymakers in Ghana have dedicated more and more attention to the development and employment of nuclear energy aimed at driving transformation and development in the various economic sectors ^[2]. The piqued interest of policymakers in investing in nuclear energy is mainly geared towards securing energy security in terms of stabilizing electricity – the positive ripple effects of such an investment on other sectors of the economy are undeniable ^[3]. Other benefits of nuclear energy include less greenhouse gas emissions compared to the production of electricity from burning fossil fuels ^[4].

Studies from the 1970s and recent research suggest that Ghana has uranium deposits in certain areas, with ongoing studies assessing whether these could be commercially viable. If Ghana were to rely on imported nuclear fuel, supply constraints would be minimal, as nuclear fuel is cost-effective, comprising only about 14% of total electricity generation expenses, far lower than the 89% for gas and 78% for coal. Additionally, nuclear power requires a small amount of fuel per unit of energy generated, and fuel can be stored for extended periods before use. These factors collectively boost energy security, making nuclear power a stable option for Ghana's energy needs ^[5]. As at 2012,

policymakers aimed at achieving one (1) gigawatts (GW) by 2030.

However, the expansion of nuclear activities brings forth significant environmental concerns, particularly regarding waste management. To mitigate potential environmental impacts, Ghana must adopt stringent legislation and align with best international practices on nuclear waste management, fostering an approach that secures environmental protection alongside energy advancement. Hence, Ghana has aligned its nuclear activities programme closely with the recommendations and guidelines of the International Atomic Energy Agency (IAEA), especially as outlined in the IAEA Milestones Approach. The Statute of the IAEA authorizes the IAEA to promote the safe and peaceful use of nuclear energy. The safe and peaceful use of nuclear energy in any given State can only be assured with the promulgation and implementation of an effective national nuclear legal framework and infrastructure ^[6]

As Ghana's energy landscape increasingly puts in place laws, policies, institutions, and measures to augment its efforts to rely on nuclear energy, it is critical to have strong and efficient waste management systems. Ghana needs to take proactive measures to address nuclear waste issues in order to prevent environmental damage, as demonstrated by lessons gained from nations with established nuclear programmes.

Background and Legal Framework

In the pursuit of nuclear activities to add nuclear energy to Ghana's mix of energy sources, the concepts of safety, security and safeguards are paramount ^[7]. Safety refers to the measures to prevent or mitigate unintended hazards, incidents, or accidents that flow from the exposure to radioactivity emanating from authorized nuclear activities. Safeguards refers to measures to prevent proliferation or State action of weaponizing nuclear energy, materials, or equipment for non-peaceful uses whilst security refers to measures to detect and prevent the intentional mishandling, theft, or sabotage of nuclear and radioactive materials by non-state elements to cause harm ^[8]. Misguided use of nuclear activities can result in devastating effects on the environment, the economy, property and the lives and livelihood of the people. The safe and peaceful use of nuclear energy can only be secured by stringent legislation which adequately provides for all facets of nuclear activities, including waste management ^[9]. Such legislation is at two levels; National Legislation and International Legislation.

Nuclear Regulatory Act

The primary national legal instrument guiding nuclear activities in Ghana is the Nuclear Regulatory Authority Act, 2015 (Act 895). This Act is integral to regulating nuclear energy, placing a strong emphasis on environmental protection. Under Act 895, the Nuclear Regulatory Authority (NRA) is responsible for overseeing safety and ensuring that nuclear activities comply with environmental standards ^[10]. The three main objects of the authority are; a) ensure that radiation and nuclear energy is used by only persons authorised under the Act, for peaceful purposes; (b) provide protection of persons and the environment against the harmful effects of radiation hazards; and (c) pursue and ensure strict compliance with the Act and the Regulations.

The Act further makes very important security and safeguards provisions. The Act prohibits the use of nuclear and radioactive material, nuclear and radioactive waste and radiations by unlicensed individuals ^[11]. This licensing process is rigorous, ensuring that all activities comply with environmental safety standards and international guidelines on nuclear waste management. Furthermore, the Act places a vast number of responsibilities on persons with authority to handle nuclear and radioactive materials ^[12]. These responsibilities are aimed towards the protection of the environment from pollution and radioactive toxins.

Act 895 requires nuclear facilities to conduct an Environmental Impact Assessment (EIA) before beginning operations. The EIA must outline how radioactive waste will be managed, contained, and disposed of to minimize risks to human health and the environment. This assessment includes a detailed analysis of the long-term environmental effects of radiation exposure, contamination risks to soil and water, and the impact of waste on surrounding ecosystems. The NRA reviews these assessments and grants approvals only if the proposed measures meet the strict environmental standards set by both national and international nuclear safety protocols.

One of the core responsibilities outlined in Act 895 is the NRA's oversight of nuclear waste management protocols. This includes setting guidelines for the handling, transportation, storage, and disposal of radioactive waste to prevent environmental contamination. Nuclear facilities

must follow strict guidelines on waste classification, with clear distinctions made between low-level, intermediate-level, and high-level waste, each with corresponding management and disposal requirements. Act 895 mandates that high-level radioactive waste, for example, must be contained in durable, corrosion-resistant containers to prevent leakage into the soil or water sources, thus protecting ecosystems from harmful radiation.

Act 895 includes provisions for emergency preparedness and response, ^[13] outlining specific procedures for handling accidental releases of radioactive materials. In the event of a nuclear accident or a significant leak of radioactive waste, the NRA is authorized to implement containment measures, inform affected communities, and coordinate with other governmental agencies to protect public health and the environment. Facilities are required to develop emergency response plans, including strategies for environmental decontamination and waste containment to prevent widespread radiation exposure.

The Act emphasizes the importance of public engagement and transparency in nuclear activities. This includes educating the public on nuclear waste management practices and making information on radiation safety and environmental protection publicly accessible. By promoting transparency, the NRA builds public trust and encourages community involvement, which is crucial for ensuring the safe and environmentally responsible handling of nuclear materials. Public involvement also ensures that local concerns, particularly environmental impacts, are considered in decision-making processes.

In the context of waste management, the Act provides that Facilities must use advanced containment structures designed to limit the spread of radiation from waste storage sites, ensuring that harmful substances do not seep into the soil or water systems. Furthermore, the Act mandates that all radioactive waste must be stored in secure facilities designed for long-term containment, thus minimizing environmental impact over time. Finally, continuous environmental monitoring ensures that radiation levels around nuclear sites remain within safe limits. Facilities are required to monitor air, water, and soil quality in the vicinity of nuclear activities.

The NRA comprises three directorates and 10 Departments. Two of these departments – Nuclear Safety, Security and Safeguards; and, Emergency Preparedness and Response – have been tasked with overseeing the development of nuclear power-related regulations to provide detailed measures on nuclear power including the safe management of nuclear waste.

Related National Regulatory Frameworks

Ghana has established a comprehensive legal framework to regulate nuclear activities and ensure environmental protection. These laws work in tandem with the Nuclear Regulatory Authority Act, 2015 (Act 895), to promote the safe, secure, and peaceful use of nuclear technology. Here is an overview of the key national laws and their impacts.

The Environmental Protection Agency (EPA) Act, 1994 (Act 490) established the EPA as Ghana's main regulatory authority for environmental protection and sustainable development. This Act mandates the EPA to prevent and control pollution, promote environmental quality standards, and conduct environmental impact assessments (EIAs) for projects that may pose environmental risks. For instance,

any project or activity with potential environmental impacts, including nuclear facilities, must obtain an environmental permit from the EPA. This ensures that activities related to nuclear energy undergo rigorous environmental assessments. The Act also requires a comprehensive EIA for all major projects to assess potential risks to the environment and public health. In the case of nuclear projects, EIAs are vital for identifying radiation risks, assessing waste management practices, and evaluating long-term impacts on ecosystems. Additionally, the EPA Act empowers the EPA to establish pollution control measures, including regulating radiation and emissions from nuclear activities to protect air, water, and soil quality.

The Radiation Protection Instrument, 1993 (LI 1559) provides the foundational regulations for radiation safety in Ghana. It was one of the earliest legal frameworks for managing radiation exposure, providing specific standards to protect workers, the public, and the environment from the harmful effects of ionizing radiation. LI 1559 sets permissible limits for radiation exposure for workers and the general public, aligning with international standards to minimize radiation risks. It includes guidelines for the safe handling, storage, and disposal of radioactive waste, helping to prevent environmental contamination. Facilities using radioactive materials must continuously monitor radiation levels and report any safety issues or incidents, ensuring early detection and response to any leaks or contamination risks.

The Hazardous and Electronic Waste Control and Management Act, 2016 (Act 917) focuses on regulating hazardous waste, particularly electronic and chemical wastes, but also extends to other types of waste that pose health and environmental risks. While not specifically designed for radioactive waste, Act 917 is applicable to any materials classified as hazardous. The Act categorizes different types of hazardous waste and establishes guidelines for their handling, storage, and disposal, ensuring public and environmental safety. Companies generating hazardous waste are responsible for its disposal, encouraging safer waste management practices. This is relevant for nuclear facilities managing mixed waste that may include both radioactive and chemical hazards. Act 917 mandates facilities to implement pollution control measures, aligning with the safety protocols required for nuclear waste management.

The Public Health Act, 2012 (Act 851) provides a comprehensive legal framework for protecting public health in Ghana. This Act covers a wide range of health-related issues, including environmental health, infectious diseases, food safety, and radiation exposure. It includes provisions for managing sources of radiation to protect the public from health risks, mandating safe practices for handling radioactive materials and reinforcing safety protocols in nuclear activities. The Act empowers public health authorities to control environmental hazards that pose health risks, including radiation hazards from nuclear waste, thereby supporting preventive measures required by the Nuclear Regulatory Authority Act. In the event of a radiation incident, the Act authorizes health authorities to conduct interventions to mitigate health risks, including environmental decontamination and medical support for affected populations.

The Minerals and Mining Act, 2006 (Act 703) regulates mining activities in Ghana, including those related to

uranium and other minerals that may be used in nuclear energy production. Although primarily focused on the mining industry, Act 703 has several relevant provisions for nuclear regulation. The Act mandates mining companies to implement measures to protect the environment, particularly when handling radioactive materials. This includes minimizing radiation exposure from mining and managing mining waste. Mining companies are also required to restore mining sites post-operation, reducing long-term environmental risks, which is relevant for uranium mining associated with nuclear fuel cycles. Additionally, Act 703 requires specific permits for the exploration and extraction of minerals, such as uranium, ensuring environmental and safety checks are met.

The Energy Commission Act, 1997 (Act 541) oversees energy policy, planning, and regulation across all energy sectors, including nuclear energy. The Act requires all energy-producing facilities to obtain a license, which includes assessments of environmental and health impacts. This licensing procedure helps ensure that nuclear facilities adhere to high environmental and operational standards. Act 541 mandates the Energy Commission to coordinate national energy policies that consider long-term sustainability, environmental protection, and energy security, creating a foundation for integrating nuclear energy into Ghana's energy strategy. The Act emphasizes the safe and sustainable production of energy, reinforcing the need for nuclear facilities to manage their waste responsibly and minimize environmental impacts.

The Factories, Offices, and Shops Act, 1970 (Act 328) focuses on workplace health and safety, extending to nuclear facilities to ensure the well-being of employees working with hazardous materials. This Act mandates safety protocols for hazardous work environments, including those involving radioactive materials, supporting radiation protection measures that minimize workers' exposure to radioactive waste. The Act includes guidelines for ventilation, radiation shielding, and contamination control, essential in environments handling radioactive materials. Regular inspections are mandated under Act 328 to ensure compliance with safety standards, reinforcing the safety measures outlined in the Nuclear Regulatory Authority Act. In addition to these key laws, other regulations complement the nuclear framework, such as the Renewable Energy Act, 2011 (Act 832), which supports a diversified energy mix and sustainable development, and the draft regulations for the licensing, design, construction, and commissioning of nuclear installations. These regulations ensure that nuclear installations meet stringent safety requirements throughout their lifecycle, from design to commissioning.

These frameworks collectively establish the foundation for Ghana's nuclear waste management regime. However, gaps persist, notably in specific regulatory provisions for handling long-lived radioactive waste and ensuring stakeholder involvement in decision-making processes. Literature has identified the need for updates in existing policies to adequately address the unique hazards associated with nuclear materials^[14]

International treaties

As alluded to earlier, to ensure peaceful and safe use of nuclear energy and effective waste management, countries must be guided by stringent National and International laws. Ghana, in demonstrating its dedication towards the

protection of the environment from the potential negative environmental impacts, is a signatory to a number of international treaties, conventions, and agreements on nuclear energy and effective waste management. These international frameworks provide guidelines and standards to ensure the safe and peaceful use of nuclear energy, particularly focusing on nuclear waste management, radiation protection, non-proliferation, and emergency preparedness. This section discusses a number of these international conventions, even though the listed conventions are not exhaustive.

The Convention on Nuclear Safety (CNS) came into force on the 24th day of October, 1996. Ghana acceded to the CNS in 2011. The agreement aims to define basic safety standards and bind Contracting Parties that operate land-based civil nuclear power facilities to maintain a high level of safety. By guaranteeing that nuclear facilities are planned, built, and run in accordance with the strictest safety regulations, this convention reduces the possibility of mishaps and radioactive dangers ^[15].

Ghana is also a signatory to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The Joint Convention is the first piece of international legislation addressing the safety of managing spent fuel and radioactive waste. Ghana pledged to manage spent fuel and radioactive waste safely when it ratified this treaty in 2011. Fundamental safety principles are established by the convention, and a peer review procedure is established to guarantee adherence to these principles. Public health is safeguarded and environmental damage is avoided as a result. ^[16]

The Convention on Early Notification of a Nuclear Accident was adopted in 1986 following the Chernobyl nuclear plant accident. The Convention on Early Notification of a Nuclear Accident establishes a notification system for nuclear accidents that have the potential for international transboundary release. Ghana acceded to this convention in 2016, ensuring that it is promptly informed of any nuclear accidents that could affect its territory. This allows for timely response and mitigation measures to protect the population and the environment ^[17].

The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, also adopted in 1986, sets out an international framework for cooperation among States Parties and with the International Atomic Energy Agency (IAEA) to facilitate prompt assistance and support in the event of nuclear accidents or radiological emergencies. Ghana acceded to this convention in 2016, ensuring that it can receive and provide assistance during nuclear emergencies ^[18].

In 2017, Ghana signed the Treaty on the Prohibition of Nuclear Weapons (TPNW) at a high-level ceremony in New York. The TPNW aims to eliminate nuclear weapons and prevent their proliferation, contributing to global peace and security. By signing this treaty, Ghana has reaffirmed its commitment to a world free of nuclear weapons ^[19].

Ghana acceded to the Vienna Convention on Civil Liability for Nuclear Damage in 2020. This convention establishes a framework for liability and compensation in the event of nuclear damage, ensuring that victims are adequately compensated and that the responsible parties are held accountable ^[20].

Ghana acceded to the Joint Protocol Relating to the Application of the Vienna Convention and the Paris

Convention in 2020. This protocol aims to provide a unified framework for liability and compensation in the event of a nuclear incident, ensuring that victims receive prompt and adequate compensation ^[21].

There is also the Protocol Additional to the Agreement between the Government of the Republic of Ghana and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons (INFCIRC/540). Ghana signed this protocol in 2004, ^[22] which enhances the IAEA's ability to verify compliance with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) by providing additional measures for safeguards and inspections.

The African Nuclear-Weapon-Free-Zone (ANWFZ) Treaty of Pelindaba established the African continent as a Nuclear-Weapons-Free-Zone. Under the Pelindaba Treaty, States are not to develop, manufacture, acquire, or possess any nuclear explosive device. States must conclude safeguards agreements with the IAEA. It was signed in April 1996 by 47 of the continent's 53 States including Ghana. The Parties also undertake to prohibit, in their territory, the stationing of any nuclear explosive device. It is part of the measures to keep Africa free of environmental pollution by radioactive wastes and other radioactive matters. Ghana also ratified the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in 2011. While Ghana is not yet a party to the African Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA), it has shown interest in regional cooperation for nuclear science and technology development.

Environmental Impacts of Nuclear Activities in Ghana

The nuclear energy cycle comprises uranium mining, fuel enrichment, reactor operation, and waste management, each with distinct environmental impacts. The first step of nuclear activities is fuel procurement which is usually derived from uranium. Ghana is reported to have identified uranium mines, especially in the areas of Mpuaso in the Ashanti Region. Despite the discovery, Ghana prefers nuclear importation to the costly nature of exploration and mining, although it has not started that option ^[23]. In contrast to other energy sources like coal or gas, Ghana's Ministry of Energy claims that nuclear fuel imports are manageable because of the low amount of fuel required per unit of electricity produced ^[24]. Furthermore, long-term storage of imported nuclear fuel promotes energy security.

The second step is nuclear power generation. The process of producing nuclear power entails carefully regulated fission reactions in the reactor, when uranium nuclei split, generating heat energy that is subsequently transformed into electrical power. Although Ghana is aggressively working toward this goal, the nation has not yet reached it. Numerous research have identified that no form of energy production or use is without an impact on the environment. In the context of nuclear activities, the major environmental challenges associated with nuclear power and sustainable development are radiation, air pollution, greenhouse gas (GHG) emissions and radioactive waste ^[25].

One of the most important parts of the nuclear energy cycle is the management of radioactive waste, especially spent fuel. In order to store and treat low- and intermediate-level waste from medical and scientific uses, Ghana established a Radioactive Waste Management Center at the Ghana Atomic Energy Commission ^[26]. The Joint Convention on

the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, to which Ghana is a signatory, serves as the foundation for its strategy to managing radioactive waste. Future waste management plans may involve collaborations for overseas reprocessing or the construction of long-term storage facilities [27].

Studies by Aboagye and Baidoo (2021) [28] emphasize that radioactive waste, if not carefully managed, can lead to contamination of water bodies and soil, affecting agriculture and biodiversity. Ghana's waste management infrastructure is currently inadequate for handling nuclear waste because it was built for non-nuclear businesses. Ghana is looking to add nuclear energy to its energy mix, thus this deficiency is concerning. Disposal procedures currently solely consist of simple containment techniques, but if the amount of nuclear waste grows, these may not be sufficient. (Ampofo & Mensah, 2022) [29].

As Ghana advances its nuclear energy program, potential environmental concerns are beginning to emerge, focusing primarily on radioactive waste management, radiation exposure, groundwater contamination, and the ecological impact of uranium exploration. Here are specific examples of environmental issues related to nuclear energy in Ghana.

1. **Radioactive Waste Management and Storage:** Ghana currently lacks a permanent radioactive waste disposal facility, which puts the environment at serious risk. There are facilities for interim storage, but the lack of permanent fixes creates worries about waste leakage or unintentional exposure [30].
2. **Radiation Exposure from Medical and Industrial Waste:** Although nuclear energy production is still under development, radioactive materials are already present in the medical and industrial sectors. Inadequate handling of these materials increases the risk of radiation exposure to workers and the surrounding population [31].
3. **Groundwater Contamination:** Concerns over groundwater contamination from mining operations are raised as Ghana explores uranium reserves, especially in regions like Mpuaso. This is because uranium can contaminate water sources, affecting the quality of drinking and agricultural water [32].
4. **Soil and Agricultural Impacts:** Radioactive materials found in uranium mining exploration have been linked to soil pollution in Ghana, which, if left unchecked, might affect local agricultural and ecosystem stability [33].
5. **Health Risks to Communities:** Exposure to low levels of radiation, particularly in communities close to uranium exploration areas, could lead to long-term health effects, including respiratory and skin conditions [34].

The current waste management system in Ghana and its suitability for nuclear waste

Ghana's current waste management infrastructure is primarily designed to handle low-level radioactive waste originating from sectors such as medical, agricultural, and industrial applications, rather than high-level nuclear power generation. As the country prepares to introduce nuclear energy into its energy mix, there are concerns about the

adequacy of this infrastructure to safely manage the byproducts of nuclear energy, which include highly radioactive materials with long half-lives.

Ghana's waste management for radioactive materials is overseen by the Ghana Atomic Energy Commission (GAEC) and the Nuclear Regulatory Authority (NRA). The GAEC has established a Radioactive Waste Management Centre (RWMC), which handles the collection, storage, and treatment of low-level radioactive waste, particularly from research, medical, and industrial sources. The RWMC is currently Ghana's main facility for radioactive waste and follows safety protocols set by the International Atomic Energy Agency (IAEA) [35]. However, this facility is limited in its capability to manage the highly radioactive waste that would be generated by nuclear power plants. High-level waste, such as spent fuel from reactors, requires specialized storage solutions due to its intensity and long-lasting radiation hazards, which the RWMC is not currently equipped to handle.

The shortcomings of Ghana's current waste management infrastructure are significant. The facilities lack the high-integrity containment and cooling systems essential for storing high-level nuclear waste, such as spent nuclear fuel rods. High-level waste requires deep geological repositories or highly controlled cooling storage environments to isolate it from the biosphere until its radioactivity reduces to safe levels over hundreds or thousands of years [36]. The RWMC's infrastructure is limited to interim storage solutions, which may not be suitable for the scale and longevity required for nuclear energy waste. Furthermore, the limited capacity of Ghana's current waste management facility raises concerns about the risk of contamination in the event of accidental releases or system failures. This highlights the need for investments in upgraded waste containment systems and dedicated high-level radioactive waste storage solutions to prepare for the anticipated nuclear waste.

Safety and environmental concerns are paramount when considering the management of high-level nuclear waste. Ghana's waste management infrastructure, while effective for lower-risk radioactive materials, lacks the extensive containment and environmental monitoring systems needed for high-level waste. This poses a potential risk of groundwater contamination and ecological harm if high-level waste were to be stored in facilities not built to contain it safely. According to GAEC reports, no deep geological repositories or permanent disposal solutions for high-level radioactive waste currently exist in Ghana, which further limits the safe long-term disposal of nuclear waste [37]. The risk of contamination becomes particularly concerning when considering Ghana's susceptibility to heavy rains and potential groundwater movement, which could spread contaminants if a leak were to occur. Robust containment facilities and comprehensive environmental monitoring systems are therefore critical to safely managing nuclear waste.

Ghana has signed several international agreements related to radioactive waste management, including the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. However, compliance with these international standards requires not only regulatory frameworks but also infrastructure that meets these standards. Ghana's current infrastructure does not yet align with the requirements for safely managing

high-level waste as recommended by the IAEA's Nuclear Safety Standards and Waste Safety Fundamentals. For Ghana to comply with these standards, significant investments are needed to develop and upgrade facilities capable of long-term high-level waste management. This includes securing financial resources, technical expertise, and partnerships to establish containment facilities similar to those in more established nuclear energy countries.

To address these infrastructure gaps, Ghana's nuclear program planners, including the Ghana Nuclear Power Programme Organisation (GNPPO), are exploring strategies for improvement. Planned improvements include the development of a dedicated high-level waste storage facility and collaborations with other countries experienced in nuclear waste disposal^[38]. Ghana is also considering partnerships with countries like Russia and South Korea to gain technical assistance for building more advanced waste management facilities. Additionally, the GNPPO is evaluating options for temporary storage of spent fuel until a permanent disposal solution, such as a deep geological repository, can be developed.

While Ghana has a foundation for managing low-level radioactive waste, its current infrastructure is inadequate for the high-level waste generated by nuclear power plants. Significant investments and developments are required to ensure the safe management of nuclear waste, compliance with international standards, and protection of the environment. Through strategic planning and international collaboration, Ghana can build a robust waste management system to support its nuclear energy ambitions. The RWMC is currently Ghana's main facility for radioactive waste and follows safety protocols set by the International Atomic Energy Agency (IAEA).

Lessons from Other Jurisdictions

Chernobyl Disaster (1986): The deadliest nuclear accident in history was the Chernobyl disaster, which happened in the former Soviet Union on April 26, 1986. Reactor 41 was destroyed by an explosion and fire caused by an abrupt spike in power during a test of the reactor systems. Large swaths of Europe were contaminated by the enormous amounts of radioactivity that were discharged. About 220,000 individuals had to leave their houses.

Lessons Learned

- The importance of stringent safety protocols and adherence to operational procedures.
- The need for robust emergency response plans and international cooperation in the event of a nuclear accident.
- The long-term environmental and health impacts of radiation exposure, highlighting the necessity for continuous monitoring and remediation efforts.

Three Mile Island Accident (1979): The Three Mile Island catastrophe happened in Pennsylvania, USA, on March 28, 1979. The partial meltdown of Reactor 21 was caused by a sequence of secondary system failures. Despite releasing only trace amounts of radioactive material, it was the biggest accident in American history.

Lessons Learned

- The critical role of human factors in nuclear safety and the need for comprehensive training and education for operators.
- The importance of effective communication and coordination among plant personnel and regulatory authorities during an emergency.
- The necessity for continuous improvement in reactor design and safety systems to prevent similar incidents.

Fukushima Daiichi Disaster (2011): On March 11, 2011, Japan experienced a strong earthquake and tsunami that led to the Fukushima Daiichi accident. Three reactor buildings were badly damaged by hydrogen explosions and fuel overheating in the reactor cores as a result of the natural disasters disabling backup diesel generators. Nearly half a million residents had to be evacuated as a result of the massive radioactive leak, which contaminated a large area. Following the accident, Japan faced an overwhelming challenge in managing radioactive waste and contaminated soil, leading to significant lessons on waste containment, long-term storage solutions, and the importance of disaster resilience in waste management^[39]

Lessons Learned

- The need for robust protection against natural hazards, including earthquakes and tsunamis, in the design and operation of nuclear plants.
- The importance of having multiple and independent safety systems to ensure redundancy in the event of a failure.
- The value of international collaboration and sharing of best practices in nuclear safety and emergency preparedness.

International Standards and Best Practices for Nuclear Waste Management

Countries around the world have adopted various strategies and best practices to manage nuclear waste effectively, aligning with international standards set by organizations like the International Atomic Energy Agency (IAEA). Here are some notable examples:

France: By reprocessing spent nuclear fuel, France has created a comprehensive nuclear waste management program that reduces waste and extracts useful elements. Additionally, a deep geological repository (DGR) for the disposal of high-level radioactive waste is being built in Bure. This strategy is in line with the IAEA's guidelines for secure and sustainable waste management^[40]

Finland: The Onkalo spent nuclear fuel repository is the first operational DGR for high-level waste in the world, demonstrating Finland's leadership in nuclear waste management. For a maximum of 100,000 years, the repository is intended to isolate radioactive materials. Finland's strategy adheres to IAEA safety standards and has an emphasis on long-term safety and environmental conservation.

Sweden: Sweden's nuclear waste management strategy includes the Swedish Final Repository (SFR) at Forsmark, which is located in rock caverns approximately 60 meters below the seabed. The SFR has been operational since 1988 and is designed to safely store low- and intermediate-level

waste. Sweden's commitment to high-integrity containment and cooling systems aligns with international best practices [41].

Japan: After the nuclear accident at Fukushima Daiichi, Japan has intensified its efforts to enhance nuclear waste management. The government is concentrating on strengthening security protocols, creating cutting-edge waste management systems, and guaranteeing adherence to global norms.

These examples demonstrate how countries are implementing international standards and best practices to manage nuclear waste effectively. By learning from these experiences, Ghana can develop a robust waste management framework that ensures the safe and sustainable use of nuclear energy.

Regulatory Bottlenecks Inhibiting the Adoption of Nuclear Waste Management in Ghana

There are several infrastructure and legal barriers to Ghana's adoption of global best practices. The primary obstacles are regulatory impediments, which include difficulties incorporating international norms into Ghana's legal system, an inadequate budget, and poor coordination between government agencies [42]. Additionally, inadequate technological infrastructure limits Ghana's ability to store and process nuclear waste effectively. Targeted reforms are necessary to mitigate these difficulties. To create a sustainable nuclear waste management system, increased government funding, interagency cooperation, and improved enforcement are essential. The adoption of international standards may proceed more smoothly when private sector partnerships are included, as they can enhance financial and technological capability. Below is an analysis of the regulatory obstacles hindering the adoption of international nuclear waste management practices in Ghana:

Fragmented Regulatory Framework

Ghana's waste management and nuclear energy regulations are still in their infancy and could appear fragmented sometimes. Nuclear safety and radioactive waste management are under the jurisdiction of the Nuclear Regulatory Authority (NRA), which was created by the Nuclear Regulatory Authority Act, 2015 (Act 895). Nonetheless, regulation overlaps and inconsistencies result from the NRA, the Ghana Atomic Energy Commission (GAEC), and other environmental authorities not coordinating well [43]. The implementation of a uniform and cohesive nuclear waste management strategy is made more difficult by this fragmentation. The requirements for the long-term storage and disposal of high-level waste, which are essential for upholding safety standards, may also not be sufficiently covered by current legislation. Currently, the emphasis is often on managing low-level radioactive waste, which is simpler and presents fewer challenges.

Insufficient Regulatory Capacity and Expertise

The absence of technological know-how and regulatory ability is one of the main obstacles to implementing global best practices. The specific expertise needed to handle complicated nuclear waste is still being developed by Ghana's nuclear regulatory bodies. This shortfall makes it more difficult to implement strict international regulations that call for highly qualified workers to oversee, inspect, and

manage nuclear waste plants [44]. Furthermore, it is challenging to guarantee compliance due to the regulatory framework's lack of strong enforcement measures, especially when it comes to the long-term security and monitoring of nuclear waste storage sites.

Limited Financial Resources

A substantial financial investment is required to establish infrastructure and human resource capability in order to implement global best practices in nuclear waste management. According to Gyekye and Annan (2021) [45], Ghana's financial limitations frequently restrict the amount of money available for research, the construction of a deep geological repository for high-level waste, and improved containment facilities. Because of this costly obstacle, regulators are unable to construct and maintain the facilities and technologies required for long-term, safe management of nuclear waste. The government's capacity to build nuclear waste management infrastructure through public-private partnerships may be constrained by the high costs of regulatory compliance, which may also discourage private sector participation in the nuclear sector.

Public Perception and Political Will

The implementation of international standards may also be impacted by public opposition to nuclear energy and waste management. It can be challenging for authorities to put critical precautions into place when the public is resistant due to misinformation, radiation risk fears, and mistrust of the regulatory system [46]. Furthermore, impeding regulatory efforts to implement best practices in nuclear waste management is a lack of political will, which may be impacted by public pressure or changing governmental objectives. Under Ghana's current legislative structure, addressing these issues has not yet received the full priority it deserves and calls for an extensive public awareness and education effort.

Mitigating Measures to Address Potential Challenges in Nuclear Waste Management in Ghana

Effective nuclear waste management is crucial for ensuring the safe and sustainable use of nuclear energy. In Ghana, several challenges impede the adoption of international best practices in this area. To overcome these challenges, targeted reforms and strategic measures must be implemented. This section discusses key mitigating measures to address these challenges and improve nuclear waste management in Ghana.

Streamlining the Regulatory Framework

To address the fragmentation in Ghana's regulatory structure, it is essential to streamline the roles and responsibilities of key stakeholders involved in nuclear waste management. Enhancing the authority of the Nuclear Regulatory Authority (NRA) and establishing clear guidelines that delineate the responsibilities of the NRA, the Ghana Atomic Energy Commission (GAEC), and other environmental agencies is crucial [47]. Additionally, the creation of a centralized database and monitoring system for radioactive waste could improve coordination between agencies and enable a more cohesive enforcement strategy. This approach would help eliminate regulatory overlaps and inconsistencies, ensuring a unified and coherent nuclear waste management strategy.

Capacity Building and Training Programs

Developing technical expertise is vital for effective nuclear waste management. This involves investing in education and training programs to build a skilled workforce capable of handling advanced nuclear technologies. Collaboration with international bodies such as the International Atomic Energy Agency (IAEA) and partnerships with countries experienced in nuclear waste management can help bridge the expert gap ^[48]. In addition, establishing local research institutions dedicated to nuclear safety and waste management can foster innovation and contribute to a better understanding of local challenges and solutions. This will ensure that Ghana's regulatory authorities have the knowledge and skills necessary to enforce stringent international standards.

Securing Financial Resources

In order to overcome financial constraints, Ghana can explore diverse funding mechanisms such as international grants, technical assistance from established nuclear countries, and the development of public-private partnerships. The establishment of a Nuclear Waste Management Fund, financed through levies on nuclear operators, can provide a sustainable source of funding for infrastructure development and research ^[49]. International financing mechanisms, such as loans from the World Bank or other multilateral organizations, can also support the development of a high-level waste repository. These funding strategies are essential for building and maintaining the necessary facilities and technologies to safely manage nuclear waste in the long term.

Increasing Public Awareness and Stakeholder Engagement

Building public trust is essential for the successful implementation of nuclear waste management strategies. A comprehensive communication plan, emphasizing transparency and the benefits of safe nuclear energy, can address public concerns. Regular stakeholder consultations, involving local communities, environmental groups, and industry players, can foster trust and co-operation ^[50]. Developing educational campaigns and community outreach programs will also help demystify nuclear energy and create a more informed populace supportive of the regulatory framework. By engaging with the public and stakeholders, authorities can build a supportive environment for the implementation of effective nuclear waste management practices.

Addressing the challenges in nuclear waste management requires a multi-faceted approach that includes streamlining the regulatory framework, building capacity and technical expertise, securing financial resources, and increasing public awareness and stakeholder engagement. By implementing these measures, Ghana can develop a sustainable nuclear waste management system that adheres to international standards. This will ensure the safe and effective management of nuclear waste, contributing to the overall success of Ghana's nuclear energy program.

Recommendations for Ghana

1. Strengthening Regulatory Enforcement and Oversight: To guarantee adherence to environmental regulations, the Nuclear Regulatory Authority must exercise

more oversight and maintain ongoing nuclear facility monitoring. Periodic assessments of waste management procedures and independent audits can improve the efficacy of regulations even more.

2. Creating an All-Inclusive National Nuclear Waste Management Plan: Ghana should give top priority to the development of a national strategy that covers every phase of the nuclear waste management process, from waste generation to ultimate disposal. This strategy ought to take into account Ghana's particular environmental situation and infrastructure constraints.

3. Promoting Global Collaboration and Information Exchange: Working with international institutions like the International Atomic Energy Agency (IAEA) can provide access to worldwide knowledge and technical assistance. Working together with more seasoned countries will yield knowledge on cutting-edge disposal techniques.

4. Investing in Nuclear Waste Treatment and Disposal Research and Development: Creating a sustainable framework requires funding nuclear waste treatment research. Innovative waste reduction and containment technologies that are appropriate for Ghana should be the main focus of R&D activities.

Conclusion

Effective waste management is critical to the sustainable development of nuclear power in Ghana. As the nation transitions to integrating nuclear energy into its energy mix, adopting best international practices and stringent legislation is paramount to safeguarding environmental and public health. This paper underscores the importance of a robust legal and regulatory framework, particularly through the Nuclear Regulatory Authority Act, 2015 (Act 895), and other statutory provisions that address the environmental impacts of nuclear activities.

Ghana's current waste management infrastructure, designed for low-level radioactive waste, is inadequate for high-level waste generated by nuclear power plants. Therefore, significant investments in infrastructure, regulatory capacity, and technological advancements are necessary. Lessons from other jurisdictions, such as the Fukushima nuclear accident and international best practices, provide valuable insights into effective waste management strategies that can be adapted to Ghana's context.

Addressing regulatory bottlenecks, enhancing capacity building, securing financial resources, and fostering public awareness are critical steps to overcoming the challenges associated with nuclear waste management. By implementing targeted reforms, strengthening regulatory oversight, and promoting international cooperation and knowledge sharing, Ghana can develop a comprehensive national nuclear waste management plan. Investing in research and development will further support the safe treatment and disposal of nuclear waste.

A long-term perspective and intergenerational responsibility are essential to ensuring the sustainable development of nuclear power in Ghana. Pragmatic measures must be taken to protect the environment and public health, ensuring that the benefits of nuclear energy are realized without compromising future generations. Through careful planning, strategic investments, and adherence to international

standards, Ghana can successfully manage nuclear waste and secure a sustainable energy future.

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