International Journal of Energy and Power Engineering
2022; 11(3): 68-76
http://www.sciencepublishinggroup.com/j/ijepe
doi: 10.11648/j.ijepe.20221103.11
ISSN: 2326-957X (Print); ISSN: 2326-960X (Online)

The Role of Nuclear Energy in Ghana's Electric Energy Mix

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To cite this article:
Edward Shitsi, Emmanuel Ampomah-Amoako, Seth Kofi Debrah, Vincent Yao Agbodemegbe, Joseph Gbadago, Felix Ameyaw. The Role of Nuclear Energy in Ghana's Electric Energy Mix. *International Journal of Energy and Power Engineering*. Vol. 11, No. 3, 2022, pp. 68-76. doi: 10.11648/j.ijepe.20221103.11

Received: April 19, 2022; **Accepted**: May 6, 2022; **Published**: May 19, 2022

Abstract: The economic growth of Ghana is linked to reliable and sustainable electric energy supply to meet industrial, administrative and domestic energy demands. This is evident from reduction in the industrial, administrative and domestic activities when there is a shortfall of electric energy demands in the country. Energy is produced from fossil fuels (coal, oil, gas), renewables (sun, wind, water) and nuclear fuel (Uranium, Plutonium, Thorium) energy sources. Fossil fuels are largely used for generating electricity, for producing fuels (oil and gas) for transportation and for providing fuels (LPG and Natural gas for cooking) for domestic use. Due to environmental concerns of greenhouse gas emissions and depletion of fossil fuel resources in addition to rapid population growth, fossil fuels alone cannot meet the energy needs of the country. Renewable sources of energy are mainly used for producing electricity and also for providing fuels for domestic use. Renewable energy is a clean energy but its reliability and sustainability cannot be guaranteed because of the variations in climatic conditions during the year. Nuclear reactors are mainly used for power generation, hydrogen production, desalination and for research (research reactors). Nuclear electricity, when introduced into the country's electric energy mix would be used for baseload electricity production. It is the only source of electric energy that can replace a significant part of the fossil fuels which massively pollute the atmosphere and contribute to the greenhouse effect. Nuclear electric energy is potentially the enabling technology for the large-scale use of renewable electricity because nuclear energy could provide electricity demands when the sun does not shine, the wind does not blow, or the rain does not fall to fill our dams. Nuclear electric energy is a clean, safe, reliable and competitive energy; and its reliability and sustainability can be ensured but has major issues of weapons proliferation, safety, waste handling and high costs of design and building of Nuclear Power Plants (NPPs) as well as public acceptance, which should be well addressed.

Keywords: Nuclear Electric Energy, Baseload Electricity Production, Renewable Energy, Fossil Fuel Energy, Nuclear Reactor

1. Introduction

The reliable and sustainable electricity energy supply is important for the economic growth of a country. Continuous electricity energy supply is needed to carry out industrial, institutional, administrative and domestic activities in every country [1-9].

Electric energy is produced in large amounts from hydro-electric power plants (water as a source of fuel), fossil fuel power plants (fossil fuels), and nuclear power plants NPPs (nuclear fuels: Uranium, Thorium and Plutonium). Figures 1, 2 and 3 show how electricity is generated by the 3 power plants. Hydro-electric power plants use water as a fuel to generate electricity, whereas fossil fuel power plants and NPPs respectively use fossil fuels and nuclear fuels to generate electrcity.

Fossil fuels are largely used to produce majority of the world's electricity. Taking into consideration the growing energy demand for traditional fossil fuels (coal, gas, and oil) under the volatile energy prices, the need to also consider other alternative energy sources is important. This is strengthened by the fact that fossil fuels is not an infinite source of energy, since various studies have indicated for example that the time peak of crude oil production is very near or has passed, although the exact timeframe is under discussion. As the global energy needs are constantly increasing, countries have the option to invest in other energy sources such as nuclear and/or renewable technologies, in order to satisfy the growing energy demands.

In terms of economics, the volatility and escalation of fossil fuel prices contribute to enhancing the attractiveness of nuclear electricity. With their very low running costs, nuclear power plants become the cheapest generation source once their capital costs are amortised. Furthermore, in terms of capital investments, the designs of new plants being built today benefit from decades of industrial experience which contributed to cost reductions.

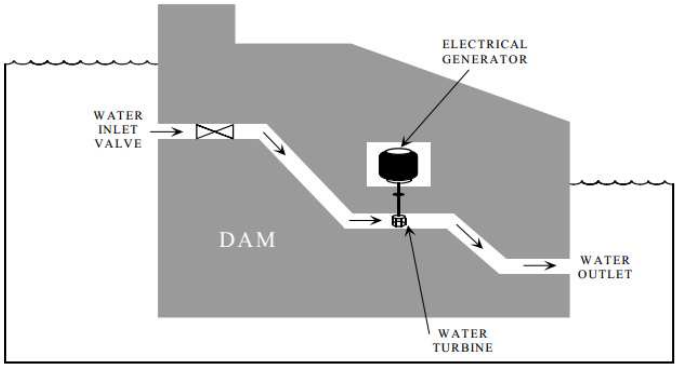

Figure 1. *Hydro-electric power plant [11].*

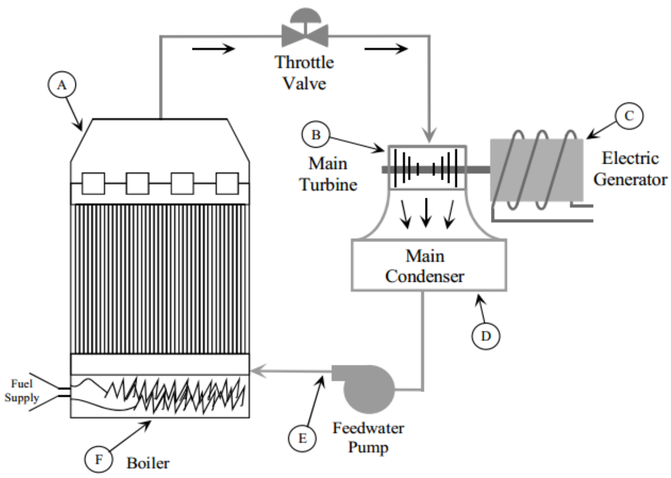

Figure 2. *Fossil fuel power plant [11].*

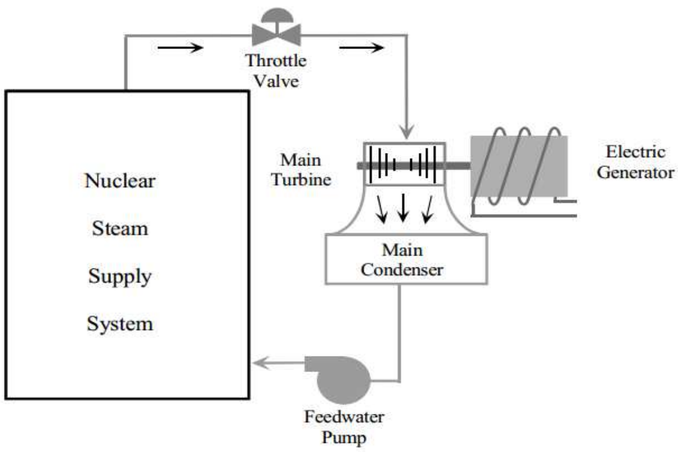

Figure 3. *Nuclear Fuel Power Plant [11].*

Ghana depends largely on hydro-electric power plants and fossil fuel power plants (thermal power plants) for electricity generation. Tables 1 and 2 show the installed electricity generation capacity as at 2021 from the two (2) major energy sources (Hydro and thermal). Solar energy sources contributed insignificant amount to the total installed capacity of 5137 MW. The country's energy demand is about 4700 MW which is expected to increase annually by 10% approximately (see Figure 4). The energy supply from the two (2) major energy sources cannot meet the country's energy needs as the demand increases with the population growth. The two (2) energy sources might not be able to also provide a minimum of 20% reserve margin in order to meet the energy demand. In 2022, electricity demands of over 22.7 thousand gigawatt hours were expected in Ghana, increasing from an estimated amount of 21.3 thousand gigawatt hours in the previous year. By 2030, it was forecast to rise even further, reaching approximately 36.5 thousand gigawatt hours, as shown in Figure 4 [10].

This paper highlights the need to introduce nuclear power into the country's energy mix to supply baseload electricity as hydro-electric and thermal (fossil fuel) power plants cannot be relied on to produce continuous baseload electricity as a result of variations in the climatic conditions and high costs of fossil fuels.

Table 1. *Electricity generation (2014 and projections for 2015) [12-15].*

Generating station/plant	**Installed capacity, MW**		**Dependable capacity, MW**	
	2014	**2015**	**2014**	**2015**
Hydro				
Akosombo	1020	1020	960	900
Kpong	160	160	140	140
Bui	400	400	380	380
Thermal				
TAPCO	330	330	300	300
TICO	220	330	200	300
TTIPP	126	126	110	110
TT2PP	49.5	49.5	45	45
MRP	80	80	40	76
T3	132	0	120	0
Sunon Asogli	200	380	180	340
CENT	126	126	110	110
Renewables				
Solar	2.5	2	2.5	2
TOTAL	2846.0	3003.5	2587.5	2703.0

Table 2. *Ghana 2020 electricity generation sources (Constructed from Energy Commission 2020 [16, 17]).*

Plant	**Installed capacity (MW)**	**Dependable capacity (MW)**	**Fuel type**
Supply from the State Volta River Authority			
Akosombo	1020	900	Hydro
Kpong GS	160	140	Hydro
TAPCO (T1)	330	300	LCO*/Gas (Thermal)
TICO (T2)	340	320	LCO*/Gas (Thermal)
TTIPP	110	100	LCO*/Gas (Thermal)
TT2PP	87	70	Gas (Thermal)
KTPP	220	200	Gas/Diesel (Thermal)
VRA Solar Plant	2.5	1.75	Solar
Total State supply	2269.5	2031.75	
Supply from Private Power Companies (Independent Power Producers)			
Bui GS	404	360	Hydro
CENT	110	100	LCO*/Gas (Thermal)
AMERI	250	230	Gas (Thermal)
SAPP 161	200	180	Gas (Thermal)
SAPP330	360	340	LCO*/Gas (Thermal)
KAR POWER	470	450	HFO* (Thermal)
AKSA	370	350	HFO* (Thermal)
BXC Solar	20	14	Solar
Meinergy Solar	20	14	Solar
Trojan	44	39.6	Diesel/Gas (Thermal)
Genser	89.5	18	Gas (Thermal)
CEN Power	340	340	LCO*/Gas (Thermal)
Amandi	190	190	LCO*/Gas (Thermal)
Total IPP Supply	2867.5	2625.6	
TOTAL (State and Private)	5137.0	4657.35	

**LCO* light crude oil, *HFO* heavy fuel oil.

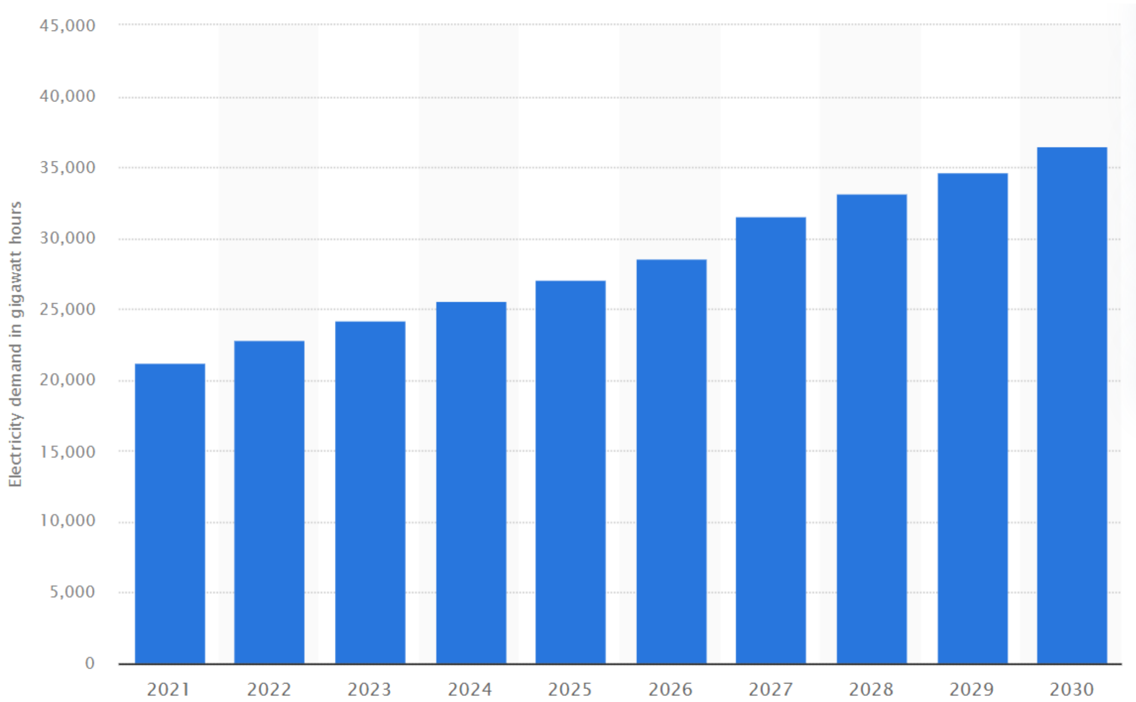

Figure 4. *Electricity Energy Demand, and Projections as at 2022 [10].*

2. Energy Sources, Their Roles and Challenges Associated with Their Usage for Electricity Generation

Energy is produced from fossil fuels (coal, oil and gas), renewables (sun, wind, water) and nuclear fuel (Uranium, Plutonium, Thorium) energy sources [18].

2.1. Fossil Fuel Energy Sources

Fossil fuel energy sources are largely used for producing fuels (coal, oil and gas) for generating electricity (mostly from Thermal Power Plants), for transportation and for domestic use (LPG and Natural gas).

Fossil fuels are non-renewable fuels and depleted with time. It is undeniable fact that the supply of these fossil fuels will reduce and cannot meet the energy demand in the future. Fossil fuels are formed when organic matter that has been buried deep within the earth are subjected to heat and pressure over millions of years. The dead organisms are buried over time and the extreme heat and pressure transformed these dead organisms into either coal, natural gas, or oil combustible materials.

Due to environmental concerns of greenhouse gas emissions, depletion of fossil fuel resources, high costs of fossil fuel power usage (fluctuating fossil fuel prices) and rapid population growth, fossil fuels alone cannot meet the energy needs of the country.

2.2. Renewable Energy Sources

Renewable sources of energy are mainly used for producing electricity (Hydro, Solar, Wind) and also for providing fuels for domestic use.

Renewable energy sources create their own energy. Renewable energy sources such as wind, water and sun are used to generate energy. The energy in these renewable energy sources are converted into mechanical power and eventually used to generate electricity. The renewable energy sources are abundant in nature and can meet the world's present and future energy needs. The challenge is how to develop the capability to effectively and economically capture, store and use the energy when needed in large quantities.

Table 3. *Costs of generating 1 kWh electric-energy from various electric-energy sources [19].*

Energy Source	**Technology**	**Capacity Factor**	**Generation Costs US cents/kWh**
Gas	CCGT	37.3	3.45
Coal	PF+fgd+CO_2 Capture	72.2	6.9-8.7
Gas	CCGT+CO_2 Capture	37.3	4.95
Uranium	Nuclear	89.8	3.9-8.0
Water	Hydro	44.2	4.2-7.8
Wind	Wind Turbines	36.0	3.0-8.0
Biofuel	Biomass IGCC	80.0	2.8-7.6
Solar	Solar photovoltaics (PV)	22.5	8.7-40.0
Solar	Solar Thermal	24.4	8.7-40.0

CCGT, combined cycle gas turbine; PF, pulverised fuel; fgd, flue gas desulphurization; IGCC, integrated gasification combined cycle.

Table 3 shows the costs of generating 1 kWh electric-energy from Renewable energy sources (water, wind, biofuel, solar) compared to that of Fossil fuel energy sources (gas, coal) and Nuclear energy source (uranium) [19]. Though the generating costs of renewables are competitive except that of solar, the capacity factors of the renewables are low (low electrical output) except that of biofuel, and hence the reliability and sustainability of the renewable energy sources cannot be assured. Also, because of the variations in climatic conditions during the year, reliability and sustainability of renewable energy cannot be guaranteed.

2.3. Nuclear Reactors

Nuclear reactors are mainly used for electricity generation (Nuclear Power Plants), hydrogen production, desalination and for research (research nuclear reactors).

Nuclear power plants generate electricity in much the same way that other thermal power plants generate electricity. The combustion of a fuel is used to generate heat, the heat is used to create steam, and the steam is used to spin turbines, which in turn generate electricity. The difference with nuclear power plants is that instead of using the combustion of a fuel to generate heat, they use nuclear fission to generate heat. Nuclear fission in simple terms is the splitting of large atoms into smaller atoms; this process releases vast amounts of energy.

Nuclear electricity, when introduced into electric energy mix, is normally used for baseload electricity production. It is the only source of electric energy that can replace a significant part of the fossil fuels which massively pollute the atmosphere and contribute to the greenhouse effect.

Nuclear electric energy is potentially the enabling technology for the large-scale use of renewable electricity because nuclear energy may be able to provide peak electricity when the sun does not shine, the wind does not blow, or the rain does not fall to fill our dams.

Nuclear electric energy is a clean, safe, reliable and competitive energy; and its reliability and sustainability can be ensured but has major issues of weapons proliferation, safety, waste handling and high capital investment costs as well as public acceptance, which should be well addressed.

Concerning safety of design and operation of nuclear power plants NPPs, as one of safety measures of design, NPPs are designed with multiple layers of safety (radiation protection barriers or walls) surrounding the reactor core or the nuclear fuels (Figure 5).

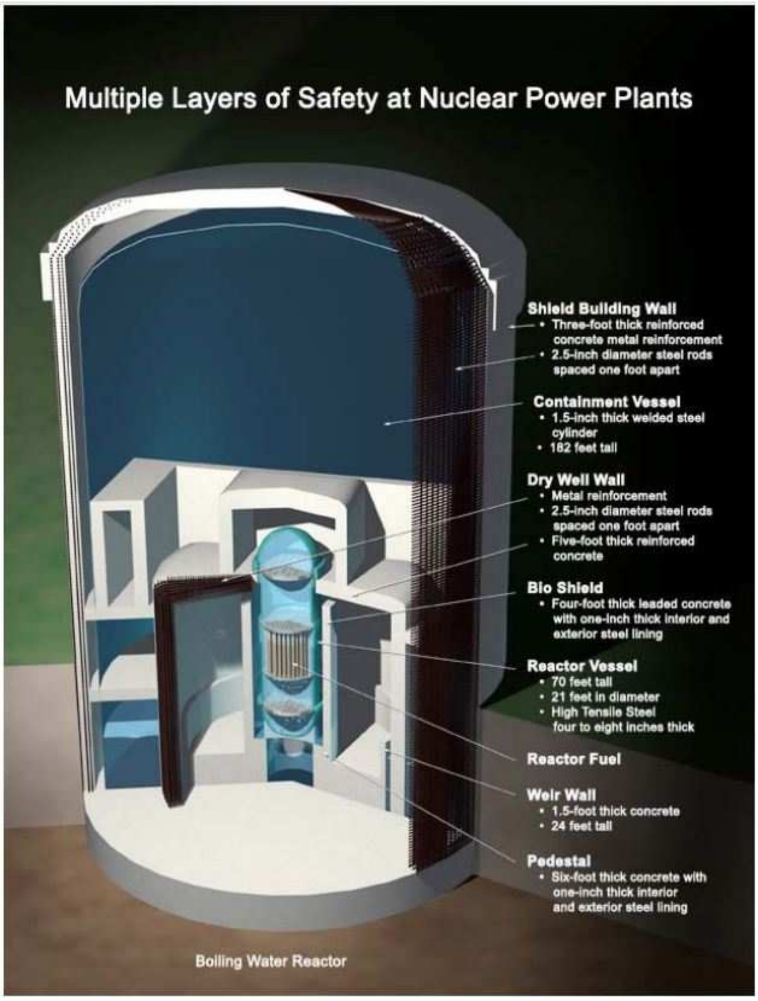

Figure 5. *Safety barriers of a boiling water reactor [20].*

Table 4 shows summary of severe accidents and fatalities associated with these accidents over period of 1969-2000 in OECD (Organisation for Economic Co-operation and Development) countries.

Table 4. *Summary of severe accidents (>5 fatalities) that occurred in fossil, hydro, and nuclear energy chains in the period 1969-2000 [20].*

Energy chain	OECD		Non-OECD	
	Accidents	Fatalities	Accidents	Fatalities
Coal	75	2,259	1,044	18,017
Oil	165	3,713	232	16,505
Natural gas	90	1,043	45	1,000
LPG	59	1,905	46	2,016
Hydro	1	14	10	29,924
Nuclear	-	-	1	31

*OECD, Organization for Economic Co-operation and Development.

This is to demonstrate that fatalities recorded by NPPs accidents are few compared to that of Hydro-electric and Fossil power plants.

Table 5 compares yearly fuel consumption by a power plant from different fuel sources to generate enough electricity for a city of 560, 000 people. A NPP used less amounts of fuel compared to other power plants.

Table 5. *Yearly Fuel Requirements for a Power Plant Generating Enough Electricity for a City of 560,000 People [21].*

Fuel	Requirements
Uranium	33 tons
Coal	2,300,000 tons
Oil	10,000,000 barrels
Natural gas	64,000,000,000 cubic feet
Solar cells	39 square miles
Garbage	7,000,000 tons
Wood	3,000,000 cords

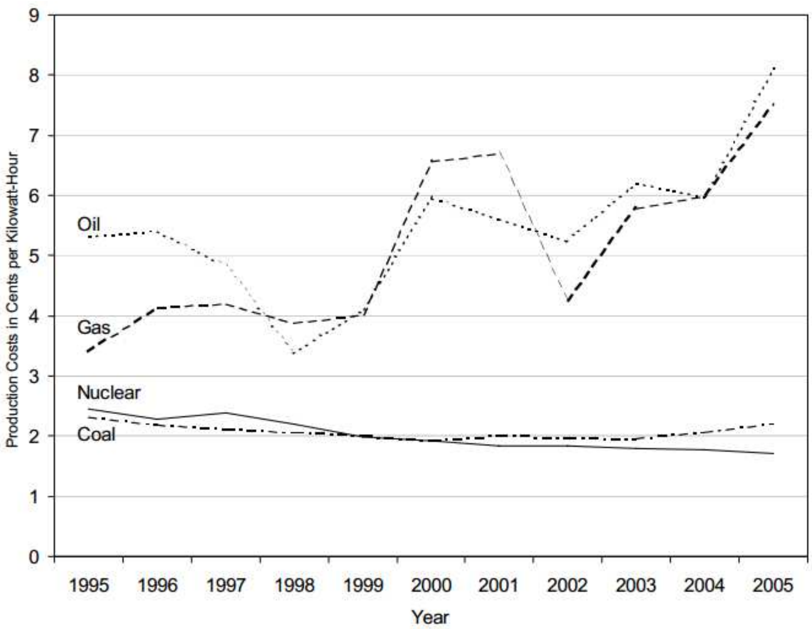

Figure 6. *U.S. Electricity Production Costs [21].*

Table 6. *Yearly Wastes Discharged from Power Plants Generating 1,000 Megawatts of Electricity [21].*

Wastes	Coal Plant	Nuclear Plant
Sulfur Dioxides, SO_2	1,000 tons	0
Nitrogen Oxides, NO_X	5,000 tons	0
Particulates	1,400 tons	0
Carbon Dioxide, CO_2	7,000,000 tons	0
Ashes	Up to 1,000,000 tons	-
Spent Fuel	-	20-30 tons

Figure 6 compares the electricity production costs of usage of fossil fuels (Coal, Oil and Gas) and nuclear fuel from 1995 to 2005, and Table 6 compares the yearly waste discharged from fossil fuel coal power plant and nuclear power plant generating 1, 000 MW of electricity. Though fossil fuel coal and nuclear fuel production costs were relatively cheap compared to the other fossil fuels Oil and Gas, the waste discharged from the fossil fuel coal power plant was large compared to that of Nuclear power plant. In fact, the waste discharge from the use of fossil fuels is imparting negatively to the environment. Fossil fuel waste discharge to the environment is the major source of global warming as a result of greenhouse gas (GHG) emissions, which are considered to be one of the main factors leading to climate change.

3. Economic Importance of Nuclear Research Reactor in National Development

The Ghana Atomic Energy Commission (GAEC) was established by an Act of Parliament, Act 204 of 1963, as the sole Agency in Ghana responsible for all matters relating to peaceful uses of atomic energy including promotion, development and utilization of the peaceful application of nuclear technologies; and advising Government on Atomic Energy Matters. The Act 204 was amended in 1993 by PNDC Law 308 mainly to enable it to create other institutes under the Commission. The founding Act 204 of 1963 has been superseded by Act 588 of 2000 to make provision for GAEC to undertake commercialization of its research and development activities. In order to establish an independent body to carry out the regulatory control of the radiation and nuclear materials in the country, an independent regulatory body known as Ghana Nuclear Regulatory Authority (GNRA) was established by Nuclear Regulatory Authority Act, 2015 (Act 895) by the parliament of Ghana. The GNRA was born out of Radiation Protection Board (RPB) who was the National Nuclear Regulatory Body but was at the same time an umbrella of GAEC. There was therefore the need for establishment of the independent regulatory body GNRA. The mandate of the regulatory body includes provision of adequate protection of the present generation, posterity and the environment against the harmful effects of ionizing and non-ionizing radiation for the safety and security of radiation sources, nuclear materials and radioactive waste; and also ensuring that radioactive sources and nuclear materials including radioactive waste from within and outside the country are properly controlled.

Ghana's Nuclear Research Reactor, known as Ghana Research Reactor-1 (GHARR-1), was commissioned in March 1995 and has since been operational. GHARR-1 is located at the Ghana Atomic Energy Commission (GAEC), Kwabenya-Accra. GHARR-1 is a Miniature Neutron Source Reactor (MNSR) used as a source of neutrons for neutron activation analysis. Generally, nuclear research reactors are small in comparison with nuclear power reactors whose primary function is to produce electricity. The long-term strategic objective of the GHARR-1 research reactor is to facilitate the development of manpower and promote plans for the introduction of nuclear power for electricity generation in the country. GHARR-1 is used mainly for Neutron Activation Analysis (NAA); Education, Training, Research and Development; and Commercial Activities.

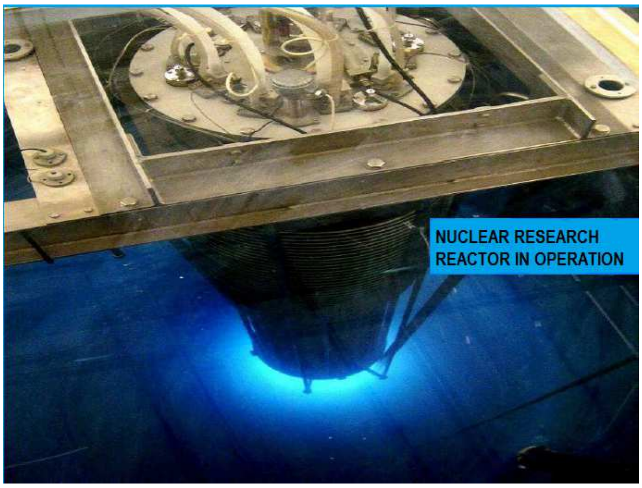

Figure 7. *Nuclear Research Reactor in operation.*

Figure 7 shows a Nuclear Research Reactor in operation.

3.1. Neutron Activation Analysis (NAA)

GHARR-1 is mainly used for Neutron Activation Analysis (NAA) to detect and measure minute quantities of an element. NAA is an important analytical technique developed with the advent of nuclear research reactors for the analysis of trace elemental content of biomedical, environmental, industrial, geological, and archaeological samples. NAA is a sensitive, accurate and precise analytical technique used for determining the amounts of different elements (major, minor, or trace) present in a sample. NAA is also a multi-elemental determination analytical technique that is suitable for determining several elements in a sample. Trace elements are vital for maintaining good health in human life. However, certain trace elements can become toxic to humans, animals and plants if present in concentrations greater than the maximum acceptable levels. Several trace elements are present in air, water, food and soil in concentrations greater than the maximum permissible level due to an increase in environmental pollution from anthropogenic activities. The quality of industrial products could also be influenced if they contain toxic elements in large concentrations more than the regulatory acceptable amounts. Thus elemental concentration determination in food and non-food samples/products using suitable analytical technique is important to consumers of these products. GHARR-1 is very helpful in study and research areas including Geochemistry, Health (Food and Nutrition) and Environment, among many others.

Geochemistry studies involves analysis of rocks, soil and water samples. Various rock types in the country are analyzed for their major, minor and trace elements for multipurpose geochemical mapping of the country. Different types of soil in the country are analyzed for various purposes including soil fertility and pollution studies. Groundwater analysis is also performed on groundwater from many parts of the country to determine whether the water from these parts of the country are safe for human consumption.

Health (Food and Nutrition) studies involve human health and nutrition monitoring by analyzing food samples (foodstuffs), water samples, and herbal plants and drugs (herbal medicine) for their elemental content. These samples used for the analyses are normally taken from mining and industrial areas.

The environmental studies focus on pollution due to mining, industrial and marine pollution. Biological indicators (lichens and seaweeds), borehole water, soil, sediments and water from streams and rivers in mining and industrial areas are used to study the degree of pollution in the country due to anthropogenic activities.

GHARR-1 is also used to analyze industrial samples such as crude oil samples to determine the trace element contents in these samples. The quality of crude oil products in the country could have severe detrimental effects on the environment and hence on human health if these trace elemental contents are not within the acceptable safety limits [22].

3.2. Education, Training, Research and Development

Students from basic schools, senior secondary schools and tertiary institutions visit the Nuclear Reactor Research Centre (NRRC) of Ghana Atomic Energy Commission (GAEC) to learn about the research reactor and acquaint themselves with the application of nuclear science. Questions including 1) what is nuclear research reactor 2) how is it operated 3) what is it used for and 4) what are the economic importance of the reactor to the national developments, among many others asked by students are addressed by the workers in charge of the reactor facility.

In order to position the country very well to develop its own human resources for management of nuclear related activities in the country, Post Graduate School of Nuclear and Allied Sciences (SNAS) under University of Ghana was established in 2006 to facilitate Nuclear Science Education and Training. Students from SNAS and other tertiary institutions undertake their research studies using the Research Reactor Facility. GHARR-1 is used for training nuclear scientists in reactor operation and maintenance, research reactor core conversion, reactor physics calculations, reactor thermal hydraulics, neutron activation analysis, radiation protection, etc., which would enable the country obtain the required manpower for its future nuclear power programs. It is also interesting to know that students from neighboring countries also use the research reactor for their post graduate studies, just to mention that the research reactor is used to train other nationals for their nuclear science education and development activities. Thus, nuclear research reactors contribute largely in nuclear science education and training of reactor operators (maintenance and operational staff) of nuclear facilities, radiation protection personnel, regulatory personnel, students and researchers.

With the addition of modern sample preparation equipment and upgrading of the reactor facility, programs such as forensic studies, low level detection, archaeological investigation, production of radioisotopes for medical and industrial use, and large sample NAA are some of the activities GHARR-1 could be used for in the near future [22].

3.3. Commercial Activities

The Nuclear Reactor Research Centre (NRRC) of GAEC is useful to many companies and industries in the country. The NRRC over the years has worked for Tema Oil Refinery, Ashanti Goldfields (Bibiani) Ltd, Volta Aluminium Company (VALCO), Bogoso Gold Ltd, West African Gas Pipeline Company, Abosso Goldfields Ltd., Environmental Protection Agency (EPA), and Panbros salt industry, etc. The NRRC would be helpful in the projects that require assessment of the toxic metallic content to ensure safety of consumers.

Nuclear research reactors can be used for other applications, such as Neutron Beam Research for Material Structure Studies and Non-destructive examination, Neutron Irradiation for Materials Testing for fission and fusion reactors, Neutron Transmutation, Geochronology, Neutron Radiography, Prompt Gamma Neutron Activation Analysis, Positron Source, and Neutron Capture Therapy [22].

Nuclear research reactors are extremely valuable training, research and technological tools. They play major roles in socio-economic improvement of people and their applications in the country for various activities including Education, Training, Research and Development should be encouraged.

4. Conclusion

Due to lack of enough rains to fill our dams throughout the year, high cost of oil prices, inconsistent gas supply to thermal power plants, and frequent breakdown of the existing old age power plants, the hydropower plants (renewable sources) and thermal power plants (fossil fuel sources) might not be able to provide baseload electricity for the country and hence the need to consider nuclear option in the country's energy mix.

With the likelihood of introduction of the Public Private Partnership (PPP) in managing electricity energy generation, transmission and distribution in the country, most of the Ghanaians might not be able to afford the high cost of electricity usage in near future in the country. The cost of Nuclear power usage is cheap once the capital cost of acquiring Nuclear Power Plant is paid-off. There is reduction in capital cost of acquiring new NPP being built today because of decades of industrial experience in design and building of NPPs.

A new electricity supply infrastructure which might not be affected by climatic and economic conditions with installed capacity of at least 600 MW power plant is needed for baseload electricity generation to significantly reduce the country's electricity energy deficit envisage in the near future. Acquiring Nuclear Power Plants for baseload electricity generation is possible option and the way forward.

In fact, no single energy source can meet our present and future country energy needs. The solution instead will come from a family of diverse energy technologies using all the three (3) energy sources that collectively limit the depletion of our natural resources or the destruction of our environment. Hence, the need to intensify efforts initiated by the country to introduce Nuclear power into the country's energy mix.

Nuclear Research Reactors are acquired and operated to gain the needed experience required to operate Nuclear Power Plants, and the country is on course in this direction.

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