(The Ghana Nuclear Power Programme Organization (GNPPO) is mandated with the task of coordinating, overseeing and administering the phase-to-phase implementation of the Nuclear Power Programme in Ghana until the commissioning of Ghana's first nuclear power plant.)

GNPPO NEWSLETTER

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ELECTRICITY GENERATION FROM NUCLEAR

BACKGROUND

Energy sources can be categorized into fossil fuels, renewables, hydro and nuclear. Ghana, over the years, has tried to meet its electricity demand with hydro and fossil-run (oil and gas) thermal plants, as well as renewables. Ghana at independence, sought and embarked on a rigorous industrialization agenda that was to thrive on the provision of an abundant, cheap and reliable electricity. This led to the building of the Akosombo Hydro-electric project which until recently, has been the main and primary base load of electricity. The second major electricity project, the nuclear power project, has not yet materialized since the overthrow of the first Republic. Nonetheless, the Ghana Atomic Energy Commission, which was established for capacity building for such purpose, has continued and still continues to do research, and provide services, in the area of nuclear science and technology.

The increase in population, advancement in technology, industrialization and demand for an improved quality of life has increased Ghana's electricity demand. The government has, therefore, decided to consider the addition of nuclear energy in its energy mix.
It must be noted that such intentions and decision, globally, undergo a meticulous process, culminating in the acquisition a nuclear power plant for the production of electricity. Nuclear energy development for civilian commercial use (i.e. electricity production) took off in the late 1950s with different countries coming up with their versions of nuclear reactors (Nuclear reactor is a device in which a nuclear chain reaction is initiated, controlled and sustained). The nuclear reaction that is usually employed in nuclear power plants to generate electricity is called fission reaction.

Nuclear energy production is similar to the way fossil fuel power plants generate electricity. In most energy generating plants, whether coal, natural gas or nuclear, some form of energy is used to heat water into steam, which is in turn used to propel a turbine. The turbine is coupled to an electromagnet called the generator and the generator produces electricity. The key difference between nuclear energy and other sources of energy lies in the fuel used to generate heat for the purpose of producing steam.

In a nuclear power plants (Figure 1), a chain reaction, involving the splitting of atoms (fission) as demonstrated in Figure 2, takes place in the reactor and leads to the release of heat. The heat from the continuous splitting of atoms is used to convert a primary coolant (water) to steam in a steam generator. The steam is used to drive the turbine which is coupled to a generator by a shaft.

The two most commonly used nuclear reactors in the world for commercial production of electricity are the Boiling Water Reactors (BWRs) and Pressurised Water Reactors (PWRs). There are variants of these PWRs and BWRs depending on the manufacturer. However, the method for generation of heat in these nuclear reactors and the subsequent conversion into electricity are the same.

There are now about 450 commercial nuclear power reactors operating in 31 countries, with more than 392,000 MWe of total installed capacity with 16943 reactor-years of operation. Among this number includes (as at August 2015); USA – 65 PWRs, 34 BWRs; France – 58 PWRs; Japan – 21 PWRs, 22 BWRs; Russia – 18 PWRs, 15 LGRs, 1 LMFR; Korea – 20 PWRs, 4 PHWRs; China – 24 PWRs, 2PHWRs, 1 LMFR; India – 1 PWR, 2 BWRs, 18 PHWRs; UK – 1 PWR, 15 GCRs; South Africa-1 PWR. This translates into 11% of the world's total electricity as shown in Figure 3

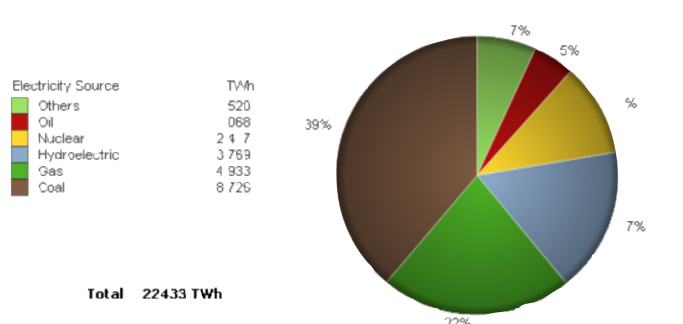

Figure 3. The share of energy sources in global electrical generation in 2014.

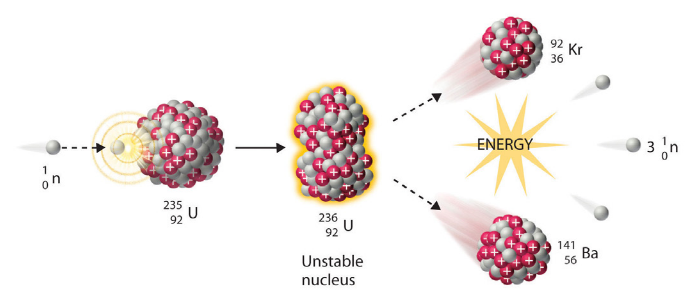

Figure 2. Two examples of fission of uranium – 235 atom

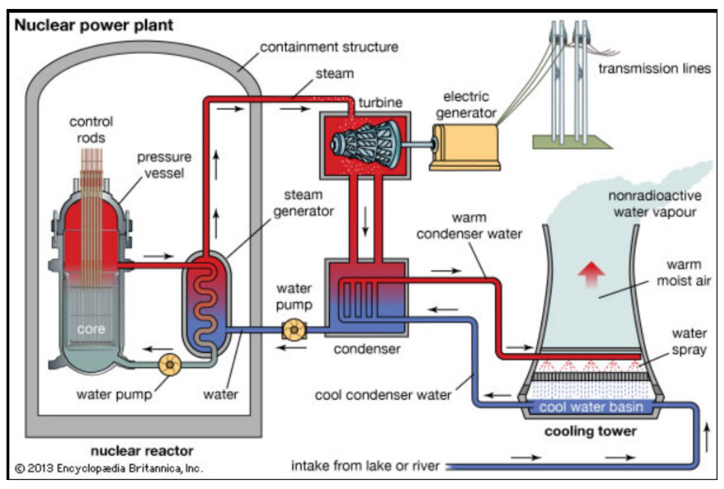

Figure 1. Schematic of a Nuclear Power plant

KEY MILESTONES IN THE EVOLUTION OF NUCLEAR POWER

- 1932 – Chadwick (UK) – Discovery of the neutron unlocked the possibility of releasing energy of the nucleus, but the mechanism was unknown.
- 1938/39 – Hahn, Meitner, Fritsch (Germany) – Discovery of fission of uranium atoms
- 2 Dec 1942 – Fermi, et al – The first controlled nuclear chain reactor – CP-1 at the University of Chicago
- 1943-1945 – Development and construction of production reactors for the Manhattan Project – first large-scale nuclear reactors (250 MWt)
- 1943-1945 – Development of uranium enrichment technology and construction of industrial-scale facilities
- 20 Dec 1951 – First nuclear electricity – EBR-1 (USA)
- Dec 1953 – US President Eisenhower's 'Atoms for Peace' speech at the UN General Assembly
- June 1954 – Beginning of operation of the first civil nuclear
- power station at Obninsk, USSR
- Jan 1955 – USSR Nautilus underway on nuclear power
- 17 June 1955 – BORAX-III produced enough steam-generated electricity to light Arco, Idaho
- 1956 – First commercial nuclear power station operational at Calder Hall, UK (50 MW)
- 29 July 1957 – Establishment of the IAEA
- 1958 – Shippingport PWR produced the first commercial electricity from nuclear power in the US (60 MW)
- 1963 – 'Turnkey' order placed for the Oyster Creek BWR (620MWe) – breakthrough in commercialization of nuclear power
- 1974 – Energy Reorganization Act of 1974 – separated promotion and regulation of nuclear energy in the US – established the US NRC as an independent agency
- 28 March 1979 –TMI accident – small failures and human error led to core melt – defense-in-depth worked
- After TMI – the Institute of Nuclear Power Operations (INPO) founded in the USA by both industry and NRC, focused much greater attention on management, operational safety, operator training, human factors, understanding accident sequences, core damage mitigation measures, emergency planning
- 26 April 1986 – Chernobyl accident in the USSR – RBMK reactor destroyed, with major radiological release and spread of contamination
- After Chernobyl – World Association of Nuclear Operators (WANO) was founded (1989)
  - *Important international conventions adopted:– Convention on Early Notification of a Nuclear Accident (1986)*
  - *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1987)*
  - *Convention on Nuclear Safety (1996)*
- 1990s and 2000s: – Deregulation of the electric power generating industry;
  - *Improved economic and safety performance of the nuclear power plants;*
  - *Increased use of probabilistic analysis – introduction of risk informed regulation and decision-making;*
  - *Increased attention to power uprating;*
  - *Increased attention to plant aging and license extension;*
  - *Recognition of the role of nuclear energy in reduction of carbon emissions;*
  - The 'nuclear renaissance';
  - Increased interest in small modular reactors
- 2011 March 11
  - *A huge earthquake and subsequent tsunami leads to station blackout and loss of all cooling capability in 4 units at the Fukushima Daiichi NPP in Japan.*
  - *All Japanese NPPs were shut down and remain shut down at this time (July, 2015). Substantial progress has been made in safety, clean-up of off-site contamination and management of radioactive water and other debris on the site*
  - *Major changes have been made in the Japanese regulatory structure and major safety upgrades to protection of plants from external events are now required.*
- 2011 – 2015:
  - *Worldwide reactions to the Fukushima Daiichi accident include re-evaluation of plant capabilities to withstand extreme external events and combinations of events heretofore considered to be beyond the design basis, improvements to accident management, emergency preparedness, communication and decision-making and regulatory structures;*
  - *A few countries have decided to phase out or reduce use of nuclear power, but others are proceeding with plans for expansion;*
  - *Nuclear power remains an attractive option for reliable, essentially emission-free base-load electrical power production. Interest in Small Modular Reactors (SMRs) as a more affordable alternative has grown.*

STATUS OF NUCLEAR POWER – NEW NPPs

There are 101 NPPs planned to be constructed in 20 countries made up of: 82 PWRs, 6 BWRs, 8 HWRs, 1 GCR and 4 LMFR. Already, there are 60 nuclear power reactors under construction.

Among the countries where new NPPs are planned/under construction are: China – 32 (31 PWRs, 1 GCR); Russia – 11 (9 PWRs, 2 LMFR); USA – 8 (6 PWRs, 2 BWRs); India – 8 (1 PWR, 5 HWRs, 1 LMFR); Korea – 6 PWRs; Turkey – 4 PWRs; UAE – 4 PWRs, South Africa – 1 PWR

ADVANCED POWER REACTORS (GEN III & III+)

Generation III and III+ reactors have significant improvements over Generation II designs in areas such as, fuel technology, thermal efficiency, modular construction, safety systems, and standardized design. Other improvement includes the implementation of passive safety features that do not require operator intervention to take effect. Features of third generation reactors include:

- Standardized, simpler designs that reduce capital cost and construction time, expedite licensing, and make the plants easier to operate and less vulnerable to upsets;
- Better operational flexibility for load-following, etc;
- Better fuel efficiency, with higher burn-up to reduce fuel use and the amount of Spent Nuclear Fuel and waste;
- Higher availability and longer life – typically 60 yrs;
- Many designs incorporate passive or inherent safety features with further reduced likelihood of core melt;
- Better aircraft crash protection.

Some examples of Generation III and III+ Reactors are provided below:

- **Advanced Power Reactor (AP-1000):**
- **Economic Simplified Boiling Water Reactor (ESBWR)**
- **Advanced Boiling Water Reactors – ABWR**
- **European Pressurized Reactors – EPR**
- **Advanced Pressurized Boiling Reactors – APWR**
- **Advanced Power Reactors – Other Designs**

GEN IV POWER REACTORS

Generation IV reactors is a class of advanced nuclear reactor systems that will offer substantial improvements in sustainability, economics, safety and reliability, proliferation resistance, and physical protection over existing commercial reactors worldwide. Generation IV reactors is expected to be ready for deployment by 2030 and includes Fast reactors, High temperature reactors, Molten salt-cooled epithermal reactor, Super-critical water-cooled reactor (thermal or fast).

FUNDAMENTALS OF NUCLEAR REACTOR SAFETY

The fundamental safety objective of nuclear reactor operation is to protect people and the environment from harmful effects of ionizing radiation. Thus, measures are taken to:

- Control the radiation exposure of people and the release of radioactive material to the environment;
- Restrict the likelihood of events that might lead to loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation;
- Mitigate the consequences of such events if they were to occur.

Nuclear Power Plants have unique safety characteristics that must be properly managed. This is important because (1) a nuclear reactor has no 'natural' or 'intrinsic' power level, and rapid power excursions are possible; (2) significant energy release continues for a very long time even after shutdown; and (3) a very large quantity of radioactive material is present in the core of a nuclear reactor after any significant period of power operation.

To address the uniqueness of the safety-related characteristics of nuclear power plants, fundamental safety functions are provided. These include

- Control of the reactivity using control rods and boron concentration to (1) control the reactor power level in operation and provide for shutdown under normal and off-normal conditions, (2) to provide for rapid shutdown ('scram') if necessary, and maintain the reactor subcritical, including in accident conditions (3) to compensate for reactivity changes due to core configuration, experiments, burnup, or temperature changes.
- Core cooling (removal of heat), including long term removal of residual heat from the core. Cooling must be sufficient to guard against cladding degradation or failure in operation, shutdown or in spent fuel storage.
- Containment of radioactive materials, control of operational discharges, and limitation of accidental releases. Much of the reactor safety enterprise deals with ensuring containment of the radioactive materials in the reactor core. Multiple physical barriers between the radioactive materials and the environment are provided in design, along with safety features intended to ensure that these barriers are not breached leading to an uncontrolled release of radioactivity;

DEFENSE-IN-DEPTH CONCEPT

Defense-in-depth is the key concept on which nuclear power plant safety is based. The objectives of defense-in-depth is to (1) compensate for potential human and component failures, (2) maintain the effectiveness of physical barriers against radioactive release by averting damage to the facilities and to the barriers themselves and (3) protect the public and the environment from harm in the event that these barriers are not fully effective. Five levels of defense-in-depth can be defined with specific objectives and essential means of achieving the objective for each level as presented in Table 1.

Level of Defense	Objective	Essential Means
1	Prevention of failures and abnormal operation	Conservative design; high quality construction; correct operation; strong safety culture
2	Detection of failures and control of abnormal operation	Correct maintenance, surveillance and testing; control and protection systems
3	Control of accidents within the design basis	Engineered safety features; emergency operating procedures
4	Control of severe plant conditions; prevention of accident progression; mitigation of severe accidents	Complementary safety design features; accident management guidelines; on-site emergency preparedness and response
5	Mitigation of off-site accident consequences	Off-site emergency preparedness and response

CONCLUSION

In view of the ever-increasing demand for energy, the dwindling levels of fossil fuel resources, price volatility and concerns with global warming the need for cleaner energy sources have become critical. Nuclear energy has emerged as one of the energy sources that could answer these multi-faceted issues. After more than 70 years of development, nuclear energy is now a well-known technology, providing an important source of emission-free energy for base-load electricity generation. However, it is acknowledged that nuclear power is a high-hazard enterprise which demands a high level of excellence in design, operation and regulation that exceeds that of any other energy technology. The current power reactors are safe and new advanced designs will provide an even higher level of safety.

UPCOMING EVENTS

INTEGRATED NUCLEAR INFRASTRUCTURE REVIEW (INIR) MISSION

- INIR Mission will enable international experts review the status and progress of work on nuclear power infrastructure development in Ghana.
- Date: 16 -21 January, 2017
- Venue: Mensvic Hotel