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Abstract

Nigeria has abundant energy resources that include natural gas, large hydro, coal, nuclear, small hydro, solar (PV and PT), and wind. However, the country's per capita electricity consumption is lower than the African continent's average. Therefore, there is a need for the diversification of the electricity supply in Nigeria. The government of the Federal Republic of Nigeria has acknowledged that nuclear energy would play a significant role in enhancing the per capita electricity generation. Consequently, the Nigeria Atomic Energy Commission (NAEC), as the national focal agency for developing and harnessing peaceful uses of nuclear energy in Nigeria, developed a strategic plan for the implementation of nuclear energy known as the National Nuclear Power Programme (NNPP). The NNPP plan was approved by the federal government of Nigeria in 2007. A critical component of the NNPP is the construction and operation of a nuclear power plant. Nuclear power plants are huge national engineering assets that require a plethora of human resources. In order to meet this need for knowledgeable and capable individuals, the NAEC, in partnership with four Nigerian universities, developed a curriculum for master's programs in nuclear science and engineering. This paper discusses the master's program in nuclear engineering that was implemented at the University of Port Harcourt. The program lasts for fifteen months and consists of twenty core courses, four electives, and one research project. To date, thirteen students have graduated from the master's program and acquired the necessary competencies with three of these graduates already enrolled in PhD programs for nuclear engineering outside Nigeria. In addition, nine papers have been published in international journals from the research work carried out by these students.

I. Introduction

Energy is one of the strategic resources necessary for the economic development and social wellbeing of any nation. Energy resources can be classified broadly as fossil (petroleum oil, gas, coal, tar sand, etc.) or renewable (hydro, solar, wind, nuclear, etc.). Nigeria has abundant energy resources. However, despite this abundance, Nigeria's per capita electricity consumption is 4 times less than the African average and

about nineteen times less than the world's average ***[1]***. The available electric power is currently about 5000MWe for a population of more than 180 million people.

To predict the energy demand in Nigeria for a 30-year period, Sambo [2] used the Model for Analysis of Energy Demand (MAED). Sambo ***[2]*** also used MESSAGE to establish the optimal fuel or source-mix required for the diversification of the electricity supply in Nigeria. The sources considered include natural gas, large hydro, coal, nuclear, small hydro, solar (PV and PT), and wind. The results indicate that electricity generation for 2005 was dominated by large and small hydro (approximately 31.3%) and the rest was provided by natural gas. The results predicted that by the year 2030, the contribution of hydro and natural gas would reduce to 8.6% and 59% respectively, while coal and nuclear, which do not currently contribute to the national electricity mix, could contribute up to 15.6% and 6.7% respectively.

The federal government of Nigeria (FGN), having acknowledged the role which nuclear energy could play in enhancing the per capita electricity generation, reactivated Act 46 of July 1976 that established Nigeria Atomic Energy Commission (NAEC) in 2006. The NAEC is mandated as the national focal agency to develop the framework and technical pathway to explore, exploit, and harness nuclear energy for peaceful uses in Nigeria. To actualize electricity generation using nuclear energy, the NAEC developed a strategic plan for its implementation called the National Nuclear Power Programme (NNPP), which was approved by the FGN in 2007 ***[3]***.

Nigeria, like other countries considering the introduction of nuclear power as part of their national energy strategy, must plan, prepare, and carefully invest the use of time and human resources to ensure success in their integration of nuclear power ***[4]***. To address this, the NAEC developed a multipronged approach, which includes: (a) formal nuclear education in universities and polytechnics; (b) on-the-job training for students; (c) facility-specific training provided by reactor-vendor organizations; (d) direct participation during project implementation; and (e) government partnerships with experienced power utility organizations for the initial operation of power plants ***[5]***.

This paper discusses the master's program in nuclear engineering that was developed by both the NAEC and the University of Port Harcourt in an effort to satisfy the manpower requirement for the implementation of the NNPP. A critical component of the NNPP is the nuclear power plant. Nuclear power plants are huge national engineering assets; thus, the master's program in nuclear engineering was designed to provide students with the necessary knowledge required for the safe, secure, reliable, and efficient operation of this nuclear asset. In Section II, we present the NNPP strategic plan. The details of the curriculum developed for the master's programme is given in Section III followed by the implementation strategy used in Section IV. The outputs from the programme is discussed in Section V and we conclude in Section VI.

II. National Nuclear Power Program Strategic Plan

The basic features of a nuclear power program (NPP) are ***[6]***:

- High initial capital cost
- Long construction period compared to other technologies
- Delayed investment returns
- Predisposed to cost overruns and construction delays in an environment of regulatory uncertainties.
- Long term government commitment and public support.
- Low maintenance and Operating cost
- Higher availability and capacity factors
- Longer lifetime of 50-60 years

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- Least potential for contributing to climate change
- Need for technical and human resource underpinning
- Need to secure nuclear material and thus, need for high safety standards, insurance and physical security.
- Commitment to an international regime of oversight governed by one standard of safety, security and safeguards and international treaties and conventions.

Despite these complex features of NPP, the federal government of Nigeria has approved and adopted the NNPP strategic action plan developed by NAEC. The aim of the strategic plan is to enable Nigeria generate electricity from NPP and develop the local capacity for internalizing nuclear power. In this regards, the strategy has the following targets ***[7]***:

- Supply of electricity from a nuclear power plant into the national grid by 2020 and building the nuclear capacity up to 4,000 MWe by 2030;
- Develop the requisite indigenous manpower and capacity to ensure the continuous availability of human capital and infrastructure base for the operation and maintenance of the nuclear power plants;
- Laying a solid foundation for the localization of nuclear technology; and
- Catalyzing the strengthening and expansion of the integrity and capacity of the national electricity grid to cope with the introduction of NPPs.

The plan is divided into three parts namely:

- Short-term which deals with the immediate activities of putting the project management structures in place to effectively launch and implement the programme;
- Medium-term which entails infrastructural development framework (see Fig. 1) and other activities that will lead to the construction and operation of the first NPP through a Turnkey contractual arrangement; and
- Long-term which addresses the issues of building multiple units, spent fuel and waste management.

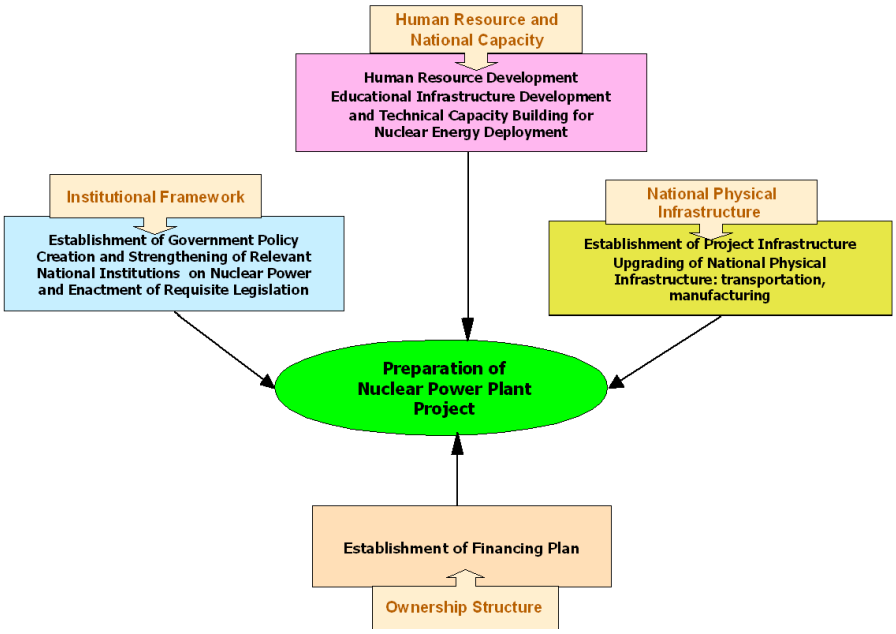

Figure 1. Condensed national nuclear power infrastructure (NPI) development framework *[6]*.

III. Curriculum Development

As seen in Fig 1, a key area of NPI is human resource and national capacity. There are no international standards regarding the content of nuclear engineering education curricula. However, there is substantial consensus among educators around the world of what constitutes a high quality nuclear engineering curriculum. A good curriculum should be capable of ***[8]***:

- educating the best candidates for the nuclear field;
- ensuring that the workforce of the future acquires the needed skills; and
- ensuring that the industry can obtain personnel with the nuclear specific skills required.

In conjunction with four universities in Nigeria (the Obafemi Awolowo University, the Ahmadu Bello University, the University of Port Harcourt, and the University of Maiduguri), the NAEC developed a common curriculum for a master's program in nuclear science and engineering ***[9]***. Each university is expected to utilize this curriculum as the minimum benchmark.

The University of Port Harcourt, through its Centre for Nuclear Energy Studies (CNES), currently offers this master's program in nuclear engineering. It is a 15-month long program, comprised of five modules:

a) General (5 courses; 10 credit units)
b) Reactor (6 courses; 14 credit units)
c) Health Physics, Safety and Security (6 courses; 11 credit units)
d) Management (4 courses; 7 credit units)
e) Laboratory and Project (4 courses; 9 credit units)

There are twenty core courses, four elective courses, and one research project (See Appendix A). As demonstrated, these courses cover the core areas of the NPP asset operation and management. These include nuclear fuel cycle, reactor technology, radiation monitoring, safety, security and safeguards.

The University Senate approved the program in 2009; however, the first set of fifteen students were not admitted until the 2011-2012 academic session. The program is sponsored by the NAEC.

IV. Implementation Strategy

A. Student Admission

Currently, there are no universities in Nigeria offering a bachelor's degree in nuclear engineering. In the interim, the NAEC organizes a three-month bridging program in nuclear science and engineering. The program is for graduate students with degrees in physics, chemistry, mathematics, mechanical, electrical, chemical, material, metallurgical and computer engineering; are below 25 years of age; and have at least acquired a second-class honors (upper division) degree. The bridging program covers core areas such as reactor theory, radiation detection and protection, nuclear and related analytical techniques, nuclear reactor thermal hydraulics and reactor design, computational methods, and nuclear materials.

Only candidates who possess the NAEC bridging program certificate and a bachelor's degree with a minimum of a 3.0 CGPA in engineering are admitted into the master's program in nuclear engineering. Using these criteria, fifteen students were admitted into the program at the CNES during the 2011-2012 academic session.

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B. Modalities for running the program

The University of Port Harcourt lacks some of the necessary infrastructure required to mount the master's curriculum presented in the previous section. Consequently, the following modalities, after due consultations with the NAEC, were adopted for running the master's program:

- A modular approach is used for teaching the students. In line with the approval given by the University Senate, this entails forty hours of lectures from Monday to Friday and a 3-hour exam on Saturday every week. The lecturers are selected from universities and industries within and outside Nigeria.
- The students will register for the program and spend the first month for the general module in the CNES, then proceed to the Nuclear Technology Centre (NTC) in Abuja for six months, and then return to the University of Port Harcourt for seminars, electives, and other courses as well as for their research project and thesis. At the NTC, the students will join their colleagues from the other three partnering universities offering this master's program for most of the core courses indicated in Tables 2 to 5.
- A joint board, chaired by the Chief Executive Officer of the NAEC, oversees the program implementation to ensure the maintenance of its standards. Other members of the joint board include the Course Coordinator at the NTC, the Deans of Science, Engineering, Post-graduate School, the Directors of Academic Planning, the respective Centre Directors from each of the partnering universities, and a representative from the NUC, the COREN, and the Nuclear Society of Nigeria.
- Lecturers are sourced from the four partnering universities, the NAEC, and the IAEA; 18 of the lecturers are from the universities in Nigeria, seven lecturers are from the IAEA expert mission, and the remaining four are from the NAEC and the NNRA.
- Upon completion of the program, the students' results are processed in accordance with the rules and regulations of the University of Port Harcourt for the award of the master's degree. It should also be noted that all answer scripts for the examinations conducted at the NTC are returned to the CNES for safekeeping.

V. Program Outputs

Out of the fifteen students admitted, thirteen students completed the program and three students withdrew from the program. From the theses submitted by the graduating students, nine (9) of those papers have been published in different international journals (See Appendix B). From the information in Table 7, it is clear the students are able to analyze, synthesize, and evaluate the knowledge they gained and apply that knowledge to nuclear related systems. We are also confident that the students have satisfied most of the specific learning outcomes at the master's level enumerated by Roberts ***[8]***. In addition, Table 7 indicates that three of the publications (SNs 6, 7 and 8) are in nuclear security.

All graduated students have either obtained a career in academics or opted to work with the NAEC and other nuclear related agencies. Three of these graduates are currently enrolled in PhD programs in South Korea, China, and South Africa. It may be pertinent to note that the Faculty of Engineering plans to start providing nuclear engineering education at the undergraduate level in the 2016-2017 academic session.

VI. Conclusion

The curriculum for the master's degree program in nuclear engineering developed by the NAEC in conjunction with four partnering universities in Nigeria has been implemented by the CNES at the University of Port Harcourt, Nigeria. To date, thirteen students have graduated from the program and have acquired the necessary competencies. Currently, nine papers have been published in international

journals from the research work carried out by the students of the program. Furthermore, the program gives Nigeria the opportunity to optimally benefit from the participation of offshore experts in critical areas where local expertise does not exist.

The partnership that exists between the NAEC and the universities provides a productive interface to quickly produce the critically needed manpower for the implementation of the program. It has also contributed to the development of the local capacity and the building of the critical educational infrastructure in the participating universities.

VII. Appendices

A. Table 1 – Table 6

Table 1. General Module

NUE808	Electrical Power System	2 units
NUE815	Nuclear Law and Legislation	1 unit
NUE830	Technical Writing and Presentation Skill	2 units
NUE832	Computing Skills	2 units
NUE834	Numerical Methods in Engineering	3 units

Table 2. Reactor Module

NUE802	Nuclear reactor dynamics and control	3 units
NUE803	Nuclear reactor theory	3 units
NUE804	Nuclear thermal hydraulics	3 units
NUE805	Nuclear reactor design	1 unit
NUE806	Nuclear reactor instrumentation and operation	2 units
NUE807	Nuclear reactor safety	2 units

Table 3. Health Physics, Safety and Security Module

NUE801	Nuclear radiation and radiological protection	3 units
NUE809	Nuclear fuel cycle	1 unit
NUE811	Radiation shielding	1 unit
NUE817	Nuclear materials	2 units
NUE8xx	Elective I	2 units
NUE8xx	Elective II	2 units

Table 4. Management Module

NUE813	Radioactive waste management	1 unit
NUE838	Renewable energy technology	2 units
NUE8xx	Elective III	2 units
NUE8xx	Elective IV	2 units

Table 5. Labs and Project Module

NUE810	Nuclear engineering laboratory	1 unit
NUE812	Nuclear engineering seminar	1 unit
NUE819	Nuclear instrumentation laboratory	1 unit
NUE899	Thesis	6 units

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Table 6. Electives

NUE840	Energy management	2 units
NUE846	Processing, disposal & storage of Nuclear waste	2 units
NUE848	Nuclear security and safeguard	2 units
NUE850	Cyber security for nuclear power plants	2 units
NUE852	Modeling and simulation laboratory	2 units
NUE854	Nuclear fuel management	2 units
NUE856	Nuclear power plant operation	2 units
NUE858	Nuclear power plant design	2 units

B. Table 7

Table 7. Published works from submitted thesis

SN	Title	Reference
1	Radiometric Survey of Aluu Landfill in Rivers State, Nigeria	Avwiri et al [10]
2	Radiometric Assay Of Hazard Indices And Excess Lifetime Cancer Risk Due To Natural Radioactivity In Soil Profile In Ogba/ Egbema/Ndoni Local Government Area Of Rivers State, Nigeria	Avwiri et al [11]
3	Evaluation Of Natural Radionuclide Content In Surface And Ground Water And Excess Lifetime Cancer Risk Due To Gamma Radioactivity	Ononugbo et al [12]
4	Risk Assessment of Abandoned Radioactive Logging Sources in Oil Wells in Nigeria	Amidu et al [13]
5	Simplified Models for Some Thermodynamic Properties of Saturated Water in a Pressurized Water Reactor	Kuye and Adibeli [14]
6	Determination of System Effectiveness for Physical Protection Systems of a Nuclear Energy Centre	Oyeyinka et al [15]
7	PPS Evaluation of An Oil Refinery Using EASI Model	Echeta et al [16]
8	Cyber-Security Evaluation for a Hypothetical Nuclear Power Plant using the Attack Tree Method	Akinola et al [17]
9	Correlations for Some Thermal Hydraulic Parameters for a Pressurized Water Reactor	Orumo et al [18]

C. Acronyms and Abbreviations

CGPA	Cumulative Grade Point Average
CNES	Centre for Nuclear Energy Studies
COREN	Council for the Regulation of Engineering in Nigeria
FGN	Federal Government of Nigeria
IAEA	International Atomic Energy Agency
MAED	Model for Analysis of Energy Demand
MESSAGE	Model for Energy Supply System Alternatives and their General Environmental Impacts
NAEC	Nigeria Atomic Energy Commission
NNPP	National Nuclear Power Programme
NNRA	Nigerian Nuclear Regulatory Authority
NPI	Nuclear Power Infrastructure
NPP	Nuclear Power Programme
NTC	Nuclear Technology Centre
NUC	National Universities Commission
NUE	Code for nuclear engineering courses
Solar PT	Solar Photothermal

Solar PV	Solar Photovoltaic

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