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### Promoting Nonproliferation of Radioactive Materials Through Knowledge Empowerment: Utilizing Research Reactor Centres for Training and Educating Students and Stakeholders Towards the Peaceful Application of Nuclear Science and Technology

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#### ABSTRACT

As one of the missions of the International Atomic Energy Agency (IAEA) to ensure the peaceful application of nuclear materials all around the world, it is on this important note that Centres with radioactive materials own up to the responsibility to educate and train individuals on the peaceful uses of these materials. Part of its mission is to provide the facility for the promotion of peaceful application of Nuclear Science and Technology to Nigerians, to enhance the development and appreciation of nuclear science, to provide high level training and improvement of skilled personnel in collaboration with the international communities/agencies, and to conduct research activities in Nuclear Science and Technology to enhance one's knowledge. In line with promoting nonproliferation of radioactive materials and devices from malicious and illicit acts, the Centre for Energy Research and Training (CERT) educates and trains students, Researchers, law enforcement agencies, armed forces, nuclear regulators and other stakeholders in Nuclear Science and Technology, ensuring the safety and security of active and disused radioactive materials. This paper reviews the establishment and mandate of CERT and its role in taking advantage of the first and only Research Reactor in Nigeria (NIRR-1) for impacting capacity building and using it as a tool for training courses, workshops, seminars and for distant learning (Internet Research Laboratory) in promoting the peaceful use of the Nuclear Science and Technology for constructive and progressive purposes in the country and beyond.

#### INTRODUCTION

Out of a total of 841 Research Reactors globally, there are about 222 Research Reactors that are operational. Twenty-four (24) are under construction/planned, 12 are on temporary shutdown, 80 are on extended/temporary/permanent shutdown and 515 are under decommissioning [8]. These countries that house these facilities are Member State of the International Atomic Energy Agency. In Africa, it has been over sixty years that Nuclear Science and Technology has been welcomed, appreciated and has metamorphosed to provide and expose scientific researchers to recent nuclear analytical techniques, supporting research and irradiation capabilities [7].

There are eight African countries with eleven Research Reactors; Egypt, Algeria and Libya have two each and other countries have one each. The Research Reactors are namely: Nur and Es-Salam in Algeria; TRICO-I<sup>1</sup> and TRICO-II<sup>1</sup> in Democratic Republic of Congo; ETRR-1<sup>1</sup> and ETRR-2 in Egypt; GHARR-1 in Ghana; IRT-1<sup>2</sup> in Libya; MA-R1 in Morocco; NIRR-1 in Nigeria; and SAFARI-1 in South Africa [7] [8]. Research Reactors primarily serve as a tool for generating neutrons that irradiates materials for elemental make-up (Neutron Activation Analysis (NAA)); production of short and long-lived radioisotopes; for education and training;

<sup>(1)</sup> On extended shutdown

research and development; and as a tool towards the establishment of a Nuclear Power Programme. They are used to produce radioisotopes for medical diagnostics (e.g. tumor treatment), industrial purposes (e.g. scanners), environmental purposes (e.g. to address pollution issues), for agricultural and land usage e.g. crop selection, production; and mitigate soil erosion [3] [4] [5]. Nuclear Research Reactors serve as a stepping stone towards the establishment of National Nuclear Power Plants as they are essential to power reactors and can be used to train scientists and engineers. They also provide experimental capabilities to study material structures and alterations; neutron flux monitoring and radiation shielding; waste control, containment and management. Research Reactors leads to the establishment and improvement of operation, utilization, maintenance, safety and security practices [7]. In modern times, Research Reactors are used to acquire nuclear data, experiments, for Research and Development, teaching and training of researchers, reactor operators, engineers, etc. in areas like Reactor/core physics and technology, reactor instrumentation, thermal hydraulics, radiation protection, etc. [7]. This is so, to promote nonproliferation and peaceful use of Radioactive materials, equipment using radioactive sources generating radioactive isotopes.

### **COMMENCEMENT OF NUCLEAR SCIENCE IN NIGERIA**

Promotion of Nuclear Science and Technology began in Nigeria by the Federal Government in 1976. Earlier in 1960, the Federal Government had setup a Radiation Monitoring Team at the Department of Physics of the University of Ibadan. During that period, the founder of Ahmadu Bello University, Zaria, Sir Ahmadu Bello visited the American Museum of Atomic Energy and Oak Ridge National Laboratory, USA. This event preceded the establishment of Ahmadu Bello University, Zaria (A.B.U.) in 1962 and can be described as a land mark of the nuclear science programme at Ahmadu Bello University, Zaria [3].

The Nuclear Science Programme Steering Committee (NSPDC) laid the solid foundation for the establishment of a Nuclear Science Programme and by extension the Centre for Energy Research and Training (CERT), Ahmadu Bello University. CERT eventually commenced in earnest through the approval of the Ahmadu Bello University Governing Council. Further developments had been rigorously pursued by the Management of the Centre till date. And as such, CERT aims to improve

Human Resource as regards education and training in Nuclear Science and Technology through Research and Development [10].

The academic endeavors at the Centre includes Nuclear Physics, Nuclear Engineering, Material Science, Radiobiology, Radiochemistry, Geology, Geophysics, Radiation Protection, Radioactive Waste Management, and Environmental Sciences. Others include Agriculture, Veterinary Medicine, Human Medicine, Archaeology and Industrial Design [1] [2] [3] [4].

### **ESTABLISHMENT OF CERT AND ITS MANDATE**

The establishment of CERT is closely associated with the historical development of Nuclear Science and Technology in Nigeria being a Member State of the International Atomic Energy Agency (IAEA). Nigeria was admitted as a member state of the IAEA in 1964. With the recognition and mandate as a Center for Excellence, a Nuclear Science Programme Steering Committee (NSPSC) was set up in 1977. The NSPSC obtained approval of the Senate of the Ahmadu Bello University and the Academic planning for the establishment of a Center for Nuclear Science and Technology (CENTECH), an appellation adopted during the meeting of NSPSC. In September 1982, this approval was sent to the University Council for its approval/accent and subsequent incorporation of the CENTECH into the laws and statutes of Ahmadu Bello University. However, CENTECH was later renamed CERT (Centre for Energy Research and Training) [1][3][10].

The NSPSC later requested and got approval for some plots of land for the permanent site for the Centre. The Committee considered the purchase of a Nuclear Research Reactor and construction of laboratories for the establishment of the Center. Some delegates from the University made up of members of the NSPSC and the consultants paid visits to some Reactor manufacturers and Research Centres with Nuclear Reactors in the United State of America, Europe, and Asia, to obtain firsthand information and working of Research Reactor types [3].

While the foundations for Nuclear Technology were been laid down at Ahmadu Bello University, Zaria, the Federal Government of Nigeria enacted the decree No. 46 (1976) towards the peaceful use of Nuclear Science and Technology by establishing the Nigeria Atomic Energy Commission (NAEC) whose functions were saddled into Energy Commission of Nigeria (ECN) from

1988 until 2004. The Act No. 19 (1995) on Nuclear Safety and Radiation led to the establishment of the Nigerian Nuclear Regulatory Authority whose responsibilities are to regulate the safe use and promotion of nuclear science and technology in the country [11][12][13]. In 1993, the Centre for Energy Research and Training was relocated to its permanent site and in 2004, CERT commissioned the first and only Nuclear Research Reactor in Nigeria (NIRR-1). In 2018, the reactor was converted from the use of Highly Enriched Uranium (HEU) to Low Enriched Uranium (LEU) fuel. The NIRR-1 currently operates with an LEU fuel powered by a 34kW thermal power [14].

Nigeria Atomic Energy Commission (NAEC) was activated and became fully operational in 2006 following the amendment Act CAP. N91 LFN (2004) which made NAEC to be the responsible establishment by enabling laws for policy formulation and decision-making in nuclear energy matters for the Government of the Federal Republic of Nigeria and legally takes the ownership of NIRR-1 as operated by CERT. This has been fully functional and operating well till date. CERT has since been properly established as a nuclear research institution with facilities for the conduct of research and a managerial system responsible for the day to day running of the Centre. CERT's mandate is *"To promote the application of Nuclear Science and Technology by providing facilities for training of Nigerians for the development of agriculture, health, mineral resources, industries, power supply and other sectors of the Nigerian economy; to provide high level training and development of strategic personnel in collaboration with the international community/agencies; to conduct research in Nuclear Science and Technology for the advancement of knowledge"* [2][4].

## **CAPACITY BUILDING, RESEARCH AND DEVELOPMENT**

### **Education and Training**

Since the establishment of CERT, it has had several collaborations with national international organizations to promote its mandate. NIRR-1 (a Miniature Neutron Source Reactor (MNSR)) has been used in educating students, training and retraining of Technical and Research Staff of the Centre, Reactor Operators, Nuclear Engineers, Maintenance Staff, Radiation Protection Personnel of Nuclear facilities and stakeholders (e.g. regulatory personnel, law enforcement agencies and armed forces) with affiliation to and concerned about

Nuclear Science and Technology. It is also used to further one's studies in Nuclear Science and Technology, commercial irradiation and for undergoing teaching and research projects. Several training courses were held and are still being organized by the Centre year in year out for this purpose. Education and training programmes include but not limited to: reactor physics, engineering and instrumentation; health physics and radiation biophysics; radiochemistry, waste management and nuclear security [3][7].

Postgraduate Diploma in Nuclear Reactor Science and Technology for human resources development is organized, suitable for the Nuclear Power Industry and Nuclear Regulatory Authority. The Centre provides for the University of Port Harcourt for instance, a platform for technical tours and practicals for the Post Graduate students of the University who undertake Courses in Nuclear Security (CNS). The Centre renders teaching services to departments of the University offering nuclear science and related courses. These services are also extended to the staff of some research institutes outside the University in such areas as X-ray fluorescence and elemental analysis by Neutron Activation Analysis (NAA) using NIRR-1. These various activities help in the long-term objective of the country to popularize the various applications of Nuclear Science and Technology to the national economy [3].

Undergraduate students from various institutions in the country forward requests to be accepted into the Centre to carry out their mandatory Industrial Training (IT) and Student Industrial Work Experience Scheme (SIWES) at the end of after their National Diploma Program and before their final year for a Degree Program respectively. Some of the students are accepted as the number of applicants are quite much year in year out. This occurs every academic session, every year and for about 6 to 12-month duration.

More so, staff and students from various schools and institutions are given permission on request for excursions, to have a tour of the Nuclear Reactor Facility. However, these exercises are given strict instructions on dos (e.g. wearing of lab coats and asking relevant questions) and don'ts (e.g. no taking of pictures nor eating) within the facility and everyone is to adhere to the safety and security procedures in the facility.

The mandatory one-year National Youth Service Corps (NYSC) in Nigeria, creates opportunities for Corp Members who are fresh graduates from the higher

institutions. They are sent to different parts of the country and get engaged in various Ministries, Departments and Agencies (MDA's) in the country. And as such, CERT being under the Nigeria Atomic Energy Commission (NAEC) which is a sector under the MDA, allows for Corp Members to be sent over to the Centre as a place for their primary assignment (PPA). They are coached through e.g. sample preparation stages, taught the components and parameters of the Reactor, demonstrations on how samples are sent into the Reactor via valves of the pneumatic transfer systems, shown how the irradiated samples undergo counting and analyses. However, they are not allowed to operate the Reactor.

An avenue is created to share ideas and expertise in Nuclear Science and Technology and other related fields amongst researchers, scientists, students, law enforcement agencies, armed forces, nuclear regulators and other stakeholders like staff of industries where radioactive materials/sources are utilized. This forum enables the sharing of information which promotes the merits over demerits of nuclear technology and propagates the non-proliferation and safe use of radioactive material such as uranium, americium, beryllium, cesium, strontium within the Reactor Facility.

CERT has a good relationship with the Centre for Energy and Development (CERD) located at the Obafemi Awolowo University in Ile-Ife, when it comes to sharing ideas, skills and materials that could promote the peaceful usages of the reactor, gamma-ray detectors and radioactive materials. Seminars and workshops are organized to disseminate new ideas, knowledge, impacts, usages, pros and cons of radioactive materials with associate components, etc. by learned experts, researchers or trained personnel. CERT trains and creates internship programmes for the Cadets of the Nigerian Defense Academy (NDA). CERT provides the platforms and opportunities for the students in the Physics Department to undergo training courses (e.g. Reactor physics, engineering and operation) organized by the Centre. They are also taken into the Reactor facility to see the NIRR-1, tutored on its benefits and the types of analyses it is used for e.g. Neutron Activation Analyses (NAA).

The Nigerian Nuclear Regulatory Authority (NNRA), Office of the National Security Adviser (ONSA), the Nigerian Custom Service (NCS), and the Department of State Services (DSS) are all not left out, as they are very important stakeholders in Nigeria when it comes to Nuclear Science and Technology. CERT engages with

these personnel through seminars (e.g. on installations, operation, radiation protection, utilization and maintenance of the facility and equipment), workshops (e.g. workshops for the Nationalization on Human Reliability Project on the critical sectors of the economy of concern with the Centre) and organized courses (e.g. the Executive Intelligence Management Courses (EIMC)) and trainings to promote the peaceful usage of the NIRR-1, discussions on the safety and security of radioactive materials and ways to improve on the safeguard quality and inspections [3]. The waste management facility is a major appendage of the NIRR-1 as it is where radioactive wastes are stored, sealed, monitored and recorded. Because of this, the IAEA collaborates with the Nigeria Atomic Energy Commission (NAEC) to organize workshops and training courses in CERT such as the "Regional Training Course on Conditioning and Storage Category 3 and 5 of Disused Sealed Radioactive Sources (DSRS)" to engage and enlighten participants from within and outside Nigeria. Programs and events like these are held to expose individuals to modern applications, positive utilizations, safety and security cultures when it comes to Research Reactors and radioactive materials/sources.

### **Research and Development**

The Research and Development activities at the Centre is inter-disciplinary in nature, which has influenced the academic activities in the University. Human Resources and Facilities available are organized into four Sections namely: Engineering and Instrumentation Design, Health Physics and Radiation Biophysics, Nuclear Science and Technology and Materials Science and Development in order to deliver on the mandate of the Centre.

Research Reactors as the name implies are utilized for research purposes, whether personal or group projects, theses or for Nuclear Power Programmes. Research and development are carried out in Reactor physics; nuclear reactor core calculations and application-driven design; neutronic and thermal hydraulics; modelling; neutron beams and tomography; material science and analysis of samples; Nuclear data analysis and technique optimization; Nuclear analytical techniques; analysis and experiments; Radiation transport physics and shielding research; Geochemistry and hydrochemistry; soil fertility studies and mineral exploitation, nuclear waste management, etc. [7]

NIRR-1 being the only Research Reactor is used to a great advantage to promote human resource development

and capacity building useful to the growth of the country and the world at large. Areas in which research and development can be carried out using the NIRR-1 include: Determination of elemental composition of various matrices using NAA; Neutronic analyses and thermal hydraulics studies; Geochemical Mapping of Nigerian Soils Sediments and rocks for solid natural resources and GIS Mapping of various mineralization zones in Nigeria for U, Rare earths, etc.; Environmental Assessment Techniques in baseline studies; Nuclear Code Development; Experimental Nuclear Physics; Effect of germanium crystal size on energy resolution, efficiency and peak shape of high purity germanium detector; Characterization of Irradiation Sites of NIRR-1; MCNP calculations of neutron spectrum parameters in the irradiation channels; Transient analyses under accident conditions; Measurements and evaluation of neutron-induced cross sections of threshold reactions; Computations in Reactor Analysis; Effects of temperature and control rod position on spatial neutron flux distribution; Nuclear data determination by theoretical and experimental methods; Reactor core conversion analysis; Monte Carlo N-particle (MCNP) simulation of permanent cadmium-lined irradiation channels for improved utilization of commercial MNSR facilities; Resolving discrepancies between the measured and estimated half-life of some radionuclides; Production of short-lived radioisotopes e.g.  $^{198}\text{Au}$ ,  $^{56}\text{Mn}$ ,  $^{24}\text{Na}$ ,  $^{82}\text{Br}$ ,  $^{140}\text{La}$ .; Burnup calculations and adjustment of excess reactivity (through addition of Be shims); and Effects of core excess reactivity and average temperature on the maximum operable time of NIRR-1[3][6].

As a result of the above capabilities of the NIRR-1, several research articles, published journals and theses were carried out with the use of NIRR-1. Also, various government agencies requested the Centre to carry out some projects on their behalf in specific research activities related to energy, environmental pollution and background radiation /radiation hazards. Also, CERT staff also carried out some research projects using the Research Reactor [3][4][6]. The projects were executed from the late 1980's to present. These projects are:

- i. Studies on Soil to Assess Toxic Effect of the Wastes Dumped at Koko, Bendel (Edo) State, Energy Commission of Nigeria.
- ii. Assessment of Energy Consumption in Northern Nigeria. Studies of Wood Fuel, Petroleum and Gas Pricing, Energy Commission of Nigeria.

- iii. Determination of Source of Oil Pollution in River Rido and Environs, Kaduna Refinery and Petrochemicals Company (KRPC), Kaduna.
- iv. Setting up of a Standard Laboratory for Monitoring of Radioactivity in Milk and Fish, National Agency for Food and Drug Administration and Control (NAFDAC), Oshodi, Lagos.
- v. Soil Fertility and Geochemical Mapping\*
- vi. Mineral Ore Analysis.
- vii. Radiation Mapping of Zaria and its Environs.
- viii. Bentonite Clay Characterization Research.

Furthermore, the NIRR-1 has future prospects to be utilized for several other analytical services such as:

1. Study of the levels of toxic and heavy elements in wells, rivers, bottled and public water supplies, as well as monitoring of pollutants in air, water and sediments.
2. Doping trace elements in ceramics silicon wafers.
3. Elemental analyses to examine the evidences from crime such as hair, nails and serum samples, and for the identification of the age of pottery and metal artifacts.

The concept of an Internet Research Laboratory (IRL) first commenced in the United States and Jordan in September, 2010. The IAEA observed the success and began an IRL project. They identified two host facilities in Latin America (Argentina) and Europe (France) and started effectively in 2015. Over time, other host facilities were added from Asia (Korea) and Africa (Morocco). Morocco has been assigned as the host facility for Africa. However, IRL broadcast is yet to begin in Africa but has some countries as designated guest recipients of the IRL with Nigeria, Kenya, Senegal\* and Ethiopia\* as countries concerned by the agreement of establishing an IRL for now [9]. On this, the International Atomic Energy Agency (IAEA) has finally signed a bilateral agreement with Nigeria to develop an Internet Reactor Laboratory (IRL). This was a recent agreement signed by the two parties at the 66<sup>th</sup> General Conference of the IAEA in Vienna, Austria in September, 2022. The project was facilitated by the Nigeria Atomic Energy Commission (NAEC), to present opportunities for Research and Teaching Staff and cooperating Universities, to promote human capacity

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\*Senegal and Ethiopia will join hopefully soon

building and development; and aid in acquiring more knowledge in Nuclear Reactor Physics and Engineering fields. Protocols like control rod calibration; reactor start-up demonstration; reactor power determination, approach to criticality; reactor dynamics; and reactivity measurements are to be broadcasted via Video Conferencing for the IRL in Africa. With the NIRR-1 fully operational, some additional protocols (e.g. Neutron flux monitoring in irradiation channels of NIRR-1 and Gamma-ray spectrometry with NIRR-1 Counting facilities) are suggested to be added to the protocols above [9]. This will greatly go a long way in further understanding the science of Reactors in theory and practical sessions. This will also create an impact towards Nigeria's plan to establish a Nuclear Power Plant (NPP) to improve the electricity production for the country.

## CONCLUSION

Nuclear Research Reactors in Africa can benefit a wide range of stakeholders, including universities; hospitals; research Centres and Institutes; Ministries, Departments and Agencies; Nuclear Power Plant Staff; mining industries; agricultural and environmental organizations. The Centre for Energy Research and Training (CERT) has shown great commitments and promised to execute research activities in Nuclear Science and Technology as well as other related fields. The presence of the Research Reactor facility (NIRR-1) ever since its installation, has been operating well, used for several analytical works and has not had any life threatening issues to both staff, neighboring people and environment. It has and is still serving as a facility for carrying out analyses mainly NAA for personal/group research, projects, theses, acquiring new ideas and knowledge, capacity building and development, hands-on technical know-how, training courses, workshops and a place for primary assignments. CERT has empowered both local and international individuals, played host to scholars from several countries as well as from the IAEA. The physics and advantages of the Reactor draws individuals of different cadre and scopes of life to appreciate the modern and educative utilization of the Research Reactor. CERT collaborates with other Centres, institutions and various stakeholders to enhance safe and secure application, operation, utilization, maintenance of the Research Reactor and associated radioactive sources. And in addition, educate and train nuclear scientists in reactor statics and dynamics; thermal hydraulics, health physics and radiation safety, management to prepare towards a potential national

nuclear power programme, etc. NIRR-1 will serve as the tool for the development of human resources for Nuclear Power Programme. The Research Reactor is the basics of a Nuclear Power Plant. Lastly, the Internet Reactor Laboratory will provide researchers with more information on the structure or design, numerical modelling and simulation, arrangement, installation, instrumentation and control, coding, operation and utilization of the Nuclear Reactor, etc. This will make Nuclear Science and Technology to be more appreciated and create a positive mindset towards the development of the country.

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