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Inaugural Lecture Series 193

"THE INVISIBLE TOOL"

By

J. B. Olomo
Professor of Physics

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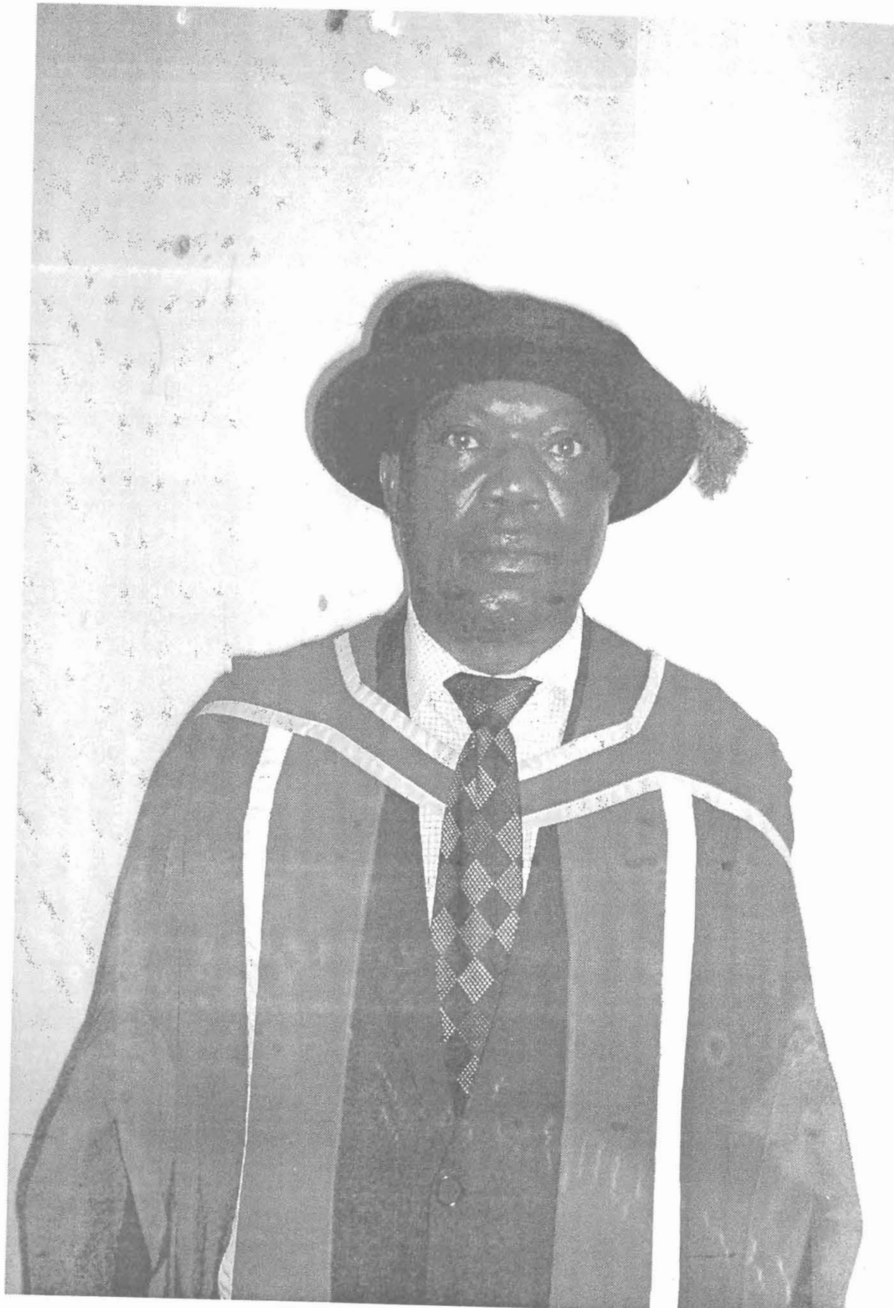

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Choices seem, at times, to have lives of their own like the one I made in March, 1973 as a final year student at the University of Ibadan (UI) where I studied physics. During my undergraduate days, we took physics courses that dealt with radiation as the energy transferred from one source to another. It was almost at the end of my training at this level that I made an unusual discovery in the University Library of a pamphlet tittled "MEDICAL PHYSICS" produced by the American Association of Physicists in Medicine (AAPM) while working on my dissertation for B.Sc degree project. I was quite fascinated by this discovery. This was because my teanage ambition, with further encouragement from my Senior Sister, Chief (Mrs.) Lucy E. Afolabi, was to become a medical doctor, an ambition I threw away when I realised that one could not make the best of medical profession if one has no sense of smell which I lack. The same reason also motivated the dislike I developed for Chemistry which I gave up at the end of the second session.

As I continued to unwrap the content of the medical physics pamphlet in the very quiet journal section of the University Library, I read about the immense direct benefits of radiation to man especially in the diagnosis and therapy of human diseases as well as sterilization of medical equipment and in research and development. I also gathered that there are two main types, namely ionising radiation and the other non–ionising. Ionising radiation can simply be defined as that radiation which would make the atoms of the matter through which it passes to be electrically charged through the ejection of an orbital electron from the atom as for example gamma– and X-rays, neutron, alpha–particle, proton, electron (beta, positron) while the non–ionising radiation is one with an energy not capable of effecting electron ejection from the atom but could only excite it to a higher energy level, such as sound– and ultrasound radiations, infrared radiation, radiofrequency, etc. Both types of radiation also have immense applications in healthcare, industry, agriculture as well as in teaching and research. During the academic journey of this inaugural lecturer, he has made use of these radiations for several years either in research and, or, in teaching.

Armed with the photocopy of some parts of the said AAPM (Medical Physics) pamphlet, I made my way to the office of Dr. A. O. Sanni, then the lecturer supervising the Federal Radiation Protection Service (FRPS) located in the Physics Department, UI, for further enlightenment on the Medical Physics Programme. I was highly stimulated by the enthusiastic discussion he had with me and the promise he gave that he could help secure a postgraduate scholarship to pursue a sound graduate training in Medical– and, or, Health Physics overseas. However, the compulsory national youth service for all fresh Nigerian graduates from tertiary institutions introduced in June 1973 by the then Federal Military Government of Nigeria thwarted the fortune of this plan.

However, in early 1974 and while still on the 12–month national youth service, I was invited for an interview for the post of Hospital Physicist in the Department of Radiation Biology and Radiotherapy of the Lagos University Teaching Hospital (LUTH) – a hospital department then headed by Prof. A. O. Fregene, a clinical (medical) physicist of several years of experience in the applications of the methods, forces and concepts of physics to the diagnosis and therapy of human diseases. I was given the job but I could not start until I had successfully completed my national youth service. And when I reported in late July, 1974, I was told

that my training would be on the job. I did not like being soundly trained before being exposed to the handling of ionising radiation and hence, I declined the offer to pick up a teaching job with the Kwara State College of Technology, Ilorin, for fourteen months.

In October, 1975, I left the shores of Nigeria for University of Surrey, Guildford, England to pursue a postgraduate training in Medical Physics. This was the beginning of an intellectual journey lasting a little over three decades now. While on this course and in early 1976, an advert made by the University of Ife (UNIFE) as the Obafemi Awolowo University (OAU) was then known, appeared in the *West Africa Magazine* for scholarships to pursue postgraduate trainings in the various aspects of nuclear technology such as nuclear physics, reactor physics, nuclear chemistry, accelerator physics, atomic and nuclear particle physics, high energy physics, material science, etc. I applied and I was awarded a scholarship having performed well at an interview organised at the then UNIFE London Office. I also gained admission to pursue a doctoral degree programme in nuclear physics specializing in nuclear and radiation safety at the Mechanical Engineering Department of Imperial College (IC) of Science and Technology (now Imperial College of Science, Technology and Medicine), University of London. This began the foray into the world of ionising radiation, which originates from a number of sources. One part is natural, the other part man- made. The natural radiation comes from the naturally occurring radionuclide headed by Uranium-238 and Thorium-232, while the other is non-series type called Potasium-40. There have always been some 70 naturally radioactive nuclides in nature, as well as in you and me. We have radioactive radium and polonium in our skeletons, radioactive potassium and carbon in our muscles, tritium and radioactive noble gases in our lungs, etc. In short, the natural radiation from the human body is strong enough to be measured with proper equipment. Therefore, the natural part has been one of the more constant features of man's environment since his ancestors emerged from the sea, while the man-made source is a consequence of the development, operation and applications of nuclear technology.

Gradually, this artificial radiation has been integrated in the steady radiation environment while human interaction with this environment has resulted in modifications which

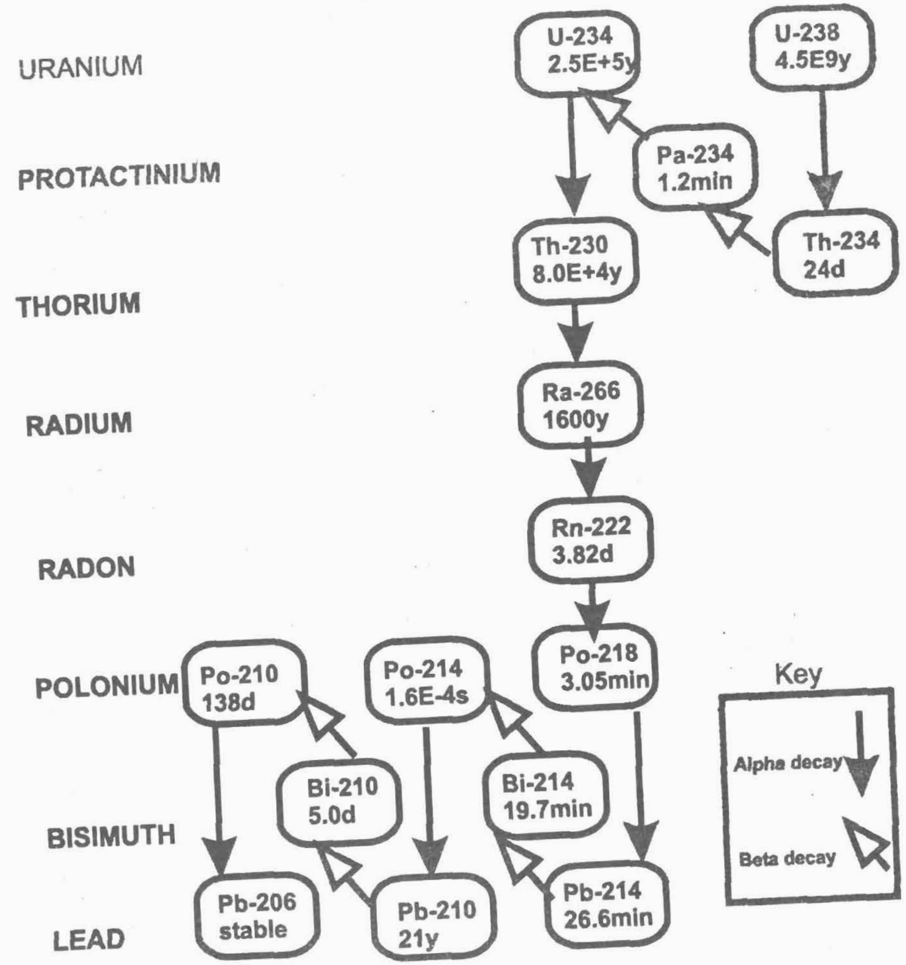

Fig 1. Principal Decay Scheme of the Uranium Series (After NCRP, 1976)

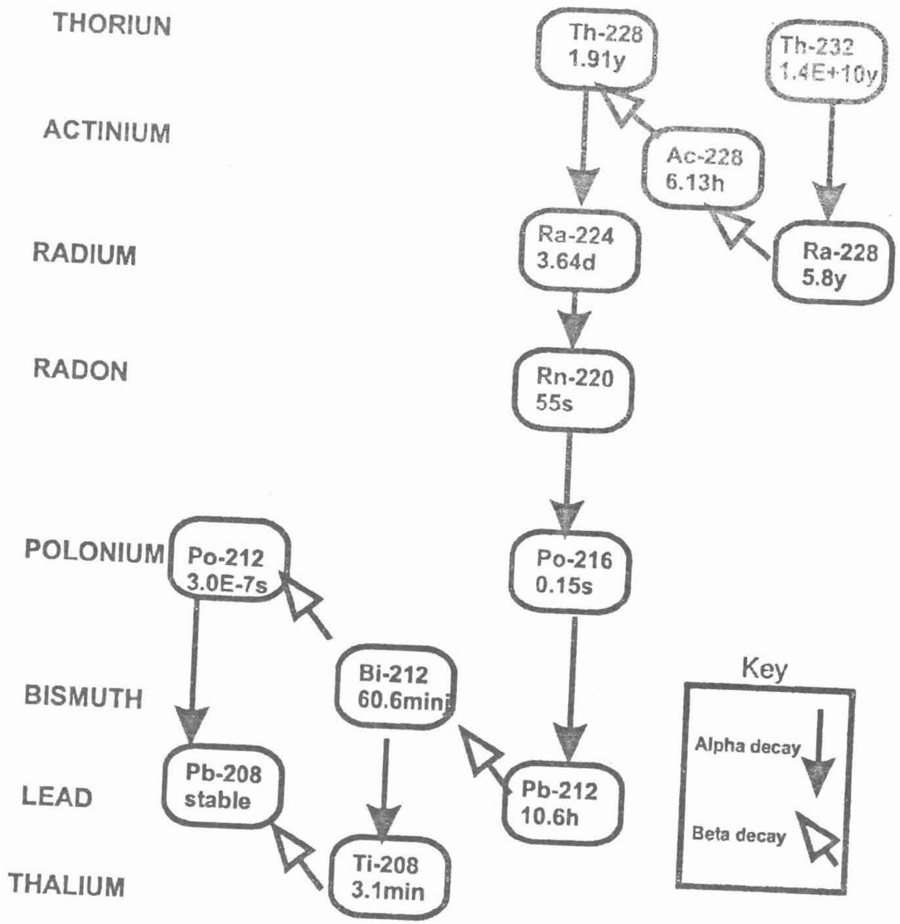

Fig 2. Principal Decay Scheme of the Thorium Series (After NCRP, 1976)

underscore the dynamics of change in nuclear safety and radiation and environmental protection for more than four decades now (Tanguy, 1988). Nuclear safety is defined as the different technical and organisational arrangements necessary to guarantee normal operation of nuclear installations without excessive discharge of radioactive effluents and excessive exposure of staff to ionising radiation, to prevent accidents, and, finally, to limit the consequences of any accidents which may nevertheless occur (Cogne, 1987). Also, radiation and environmental protection is the limiting of radiation levels in rooms and areas of nuclear installations so that the levels do not exceed allowable limits, that each source of radiation exposure must be justified in relation to its benefits, and that any necessary exposure should be kept as low as reasonably achievable (ALARA) by optimising the level of protection. The wide range of radioisotopes used as a source in a variety of nuclear technology systems became available in considerable quantities only with the advent of nuclear fission reactors. Other artificial radiation sources include particle accelerators, neutron generators, synchrotrons, isotope generators, X-ray machines, etc.

Applications of Radiation.

Albert Einstein, whose 100th anniversary of miraculous discoveries in Physics was celebrated all over the world in 2005 at the instance of the United Nations, once said:

> "Science is a powerful
> instrument. How it is
> used, whether it is a

blessing or a curse to
mankind, depends on
mankind and not on
the instrument.
A knife is useful but it
can also kill".

I like to give a variant to the above statement of Einstein that: Radiation is a powerful tool. How it is used, whether for peaceful purpose to enhance the living standard or for warfare, depends on mankind and not on the tool. Radiation is tremendously useful in all areas of socio-economic development such as in energy, healthcare, agriculture, industry, and education as in teaching and research, etc but it can also kill if employed destructively as in weaponry. It is necessary to remind ourselves that our essential needs remain energy, water, food, shelter, clothing, health and education. After all these are the things which add to the quality of life, according to our personal tastes.

Radiation role in sustainable development of energy.

Energy, in particular electrical energy, is a physics concept of the greatest importance to man, a concept that is fundamental to every field of science and technology. Economic growth and social development has gone hand in hand with increased energy used per capital, particularly in developing countries. Electrical energy is in fact our vertebral column, our spinal cord; without it our daily life is worthless; with it we produce a bountiful harvest of joy of development. The world, especially the developing part in which Nigeria is noted, is short of energy; several day, if not several week–power cuts are very common in many parts of

Nigeria even now that the present federal government promised a change for better in energy supply. No doubt, there is an improvement but serious problems still exists. A pertinent question to ask is what is the answer?

Energy resources other than fossil are needed. This is because the development of the economy in Nigeria rests, amongst others, on the provision and use of energy and a growing control over that provision and use in order to protect the environment. So, in effect, adequate energy production and environmental protection are vital to economy and society of Nigeria.

During the last five decades, the world's population, which has been on the increase, has nearly doubled. This has a direct effect that world energy consumption has increased even more rapidly, having more than quadrupled over the same period. It is quite frightening to know that this increase in energy consumption as compared to population growth has been taking place proportionately faster in the developing countries over the past 35 years than in those that are already industrialized. In the case of Nigeria, energy consumption, both domestically and industrially, is usually, on an astronomical increase whenever there is an improvement in worker's wages because of the consequent acquisition of domestic appliances and improved industrial outputs to meet various demands.

This clearly indicates that initial development requires energy in increasing per capital quantities as efforts are made to make quantum improvements in the welfare of the country and its people. If these trends of increasing electrical consumption on an overall sporadic increase in Nigerian population and sound development of the nation continue as expected in a democratic setting, conventional energy resources used to generate electricity, i.e. hydro and fossil fuels – coal, oil, natural gas, may have to be critically assessed in terms of power generation capacity and the consequence for the environment, and then compare it with nuclear systems (fission and fusion reactions) which could offer effective sources of energy for Nigerian society when fully harnessed. The following energy sources have been and are still playing formidable roles in the sustainable supply of man's energy needs; hydroelectric power, solar energy, coal and petroleum energies, geothermal energy, wind power, ocean energy, biomass (energy from wastes), etc.

However, hydroelectric projects often are combined with flood control and irrigation projects and, therefore, must involve the evaluation of the total environmental effects of the project as its undesirable effects include upstream flooding of river valleys, downstream water flow reduction, impact on the area required for the lake and the effects of long electric transmission lines from the project site to the area where the electric power is used.

Gathering sunlight and providing it in useful form when needed at a competitive cost is the principal challenge to solar energy technology. The disadvantage of the utilization of solar radiation is its dispersal over the surface area of the earth because the land area required to collect significant amount of energy is large. However, the issues that will have a significant impact on whether coal can be used as the primary fuel in the 21st century are whether:

- SO_2 emissions can be controlled at electric power plants;

- Strip mining can be permitted where reclamation can be adequate;
- The mines can attract enough labourers to do the work;
- Research and development of conversion processes for producing synthetic fuels from coal can proceed without much delay;
- Water is available and price competition can be met; and
- Capital is available for investment.

Geothermal stream carries with it a number of atmospheric pollutants including carbon dioxide, mercury and radon. The disposal of geothermal waste water from hot-brine plants usually constitutes a problem because of its mineral content which could be as high as 25%. Although wind generators do not produce air or water emissions, planners often face public opposition since the larger turbines do present a visual impact on the landscape, emit acoustic noise, generate electromagnetic interference and present a hazard to birds.

The tapping of the energy of the ocean is a difficult and complex process, and the necessity of collecting the widely dispersed energy would make for high costs. And because of significant capital requirements and risks inherent in an unproven technology, no commercial plants have been completed to date. In addition, this technology poses some environmental concerns about effects on sea life and atmospheric release of carbon dioxide stored in deep ocean waters. The ultimate potential of municipal solid waste incineration and landfill gas plants as an energy source, is limited both by public concern over emissions and concentrated sources of solid waste.

Nuclear Electricity.

Of all the major new sources of energy, nuclear fission has received the most financial support since 1945 and is correspondingly the best developed technology. The development of nuclear fission power dates back to the 1940s. Nevertheless, nuclear fission has substantial advantages over traditional sources of energy just highlighted above. Nuclear plants do not emit particulates or sulphur oxides, as do fossil – fuel plants. The fuel requires less mining and thus results in less disruption of the environment. Nuclear safety rests on many pillars. A proven design, comprehensive quality assurance and control measures during component manufacturing and plant construction are some of the most important contributors to safe operation of a nuclear power plant. A complementary programme during plant operation called inservice inspection, is another very important factor in the field of nuclear safety. New generation of nuclear power plants are now built with inherent safety because safety of nuclear technology has become the focus of the international community since the worst ever civil nuclear accident at the Chernobyl–4 nuclear power plant in Kiev, Ukraine, on 26 April, 1986.

The emphasis today in nuclear safety efforts is rather switching from establishments of standards and quality assurance to accident prevention through improved operational safety and accident mitigation. The safety of the radioactive wastes produced during reactor operation has also been perfected through the combined efforts of regulatory bodies headed by the International

Commission on Radiological Protection (ICPR) and assisted by the International Atomic Energy Agency (IAEA).

Thus, there are tremendous benefits of nuclear–generated electrical energy for Nigerian society provided the safety requirements are strictly adhered to through the effective enforcement of the new regulatory law – Nuclear Safety and Radiation Protection Law of 1995 by the competent body, the Nigerian Nuclear Regulatory Authority (NNRA). Fusion energy is in a different category from all other options as there is yet to be built a practical reactor. Because of the high efficiency of energy production and the abundance in nature of fusion fuel, Nigeria should start meaningful work on research and development of this energy option so that she could safely benefit from it when its technology is fully developed. However, physicists have not made it work in a controlled way, and the engineering development looks like taking at least 20 years from when they do. The people of Nigeria cannot wait that long.

Hydrological Studies Using Isotopes.

Sufficient water supplies is a critical factor for sustaining the life of plants, animals, and humans. Signs indicate that as human and animal populations grow, the world's water problems are becoming dramatically worse.

Not only are water supplies becoming more scarce, their quality is being degraded. Run-offs from agricultural lands packed with pesticides and fertilizers pollute rivers, streams, and lakes. Storm water flowing from cities and towns carries sewage, heavy metals, oils, hydrocarbons, garbage, chemicals, and organic wastes from animals and dust. Clearly, there is the impending need to intensify efforts to protect existing water resources, develop new sources of sustainable water supplies, and improve water distribution and control.

The assessment of water resources is particularly important in many developing countries where conventional hydrological data are insufficient but in many other countries, most available water resources are known and exploited, while new, non-explored resources are most probably limited. Therefore, the only way to cope with water demand is to protect the existing resources of crucial importance in both industrialized and developing countries. The problem is two-fold: protection of water quality, by avoiding or reducing the risk of contamination of water bodies; and protection against depletion of water resources, by means of sustainable exploitation. Radiation techniques through the use of suitable isotopes play an important role in the assessment, management, and protection of water resources.

Radiation sources such as isotopes are a powerful tool to study water bodies, allowing a better appraisal of their capacity and more rational exploitation. They also can be used to evaluate the risk of contamination and to investigate the movement and behaviour of contaminants. More importantly, isotopes help to identify flow patterns and to distinguish between water movement and contaminant movement, which is usually slower due to interaction with the rock matrix.

Environmental Monitoring and Management Techniques.

Nuclear analytical techniques such as instrumental activation analysis (INAA), proton–induced X-ray emission

(PIXE), energy dispersive X-ray fluorescence (EDXRF), etc, are not only sufficient to answer all the questions that one might wish to ask about toxic heavy metals in human environment but also have unique properties which enable them to determine many of the important constituents of non-radioactive solid wastes (e.g. coal fly ash and mine tailings) and to explore how toxic and other trace elements can be removed from them before discharge into the surrounding environment.

They are also the techniques of choice for several important kinds of study of air pollution – for example, determining the composition of airborne particulate matter, identifying individual pollution sources, and estimating the long-range transport of air pollutions. Finally, nuclear analytical techniques have important applications in the direct assessment of human exposure to toxic trace elements (as for instance occupational exposure in the workplace or consumption of contaminated foodstuffs).

Nuclear analytical techniques are also involved in the determination of natural and man–made radionuclides in the environment and food. This work has received extensive attention since 1986 following the Chernobyl–4 nuclear reactor accident. It involves the use of techniques such as gamma spectrometry, using sodium iodide and germanium detectors; alpha spectrometry, using silicon surface barrier detectors; beta emission rate measurements, using anti-coincidence equipment; liquid scintillation counting; and chemical separation techniques for different radionuclides. Marine pollution poses huge practical challenges in order to measure individual trace components within this mixture and to obtain data on their dynamics. This is because the information is essential for understanding marine and radionuclide affinity and for investigating the transport, fate, and effects of marine contaminants. Nuclear and isotopic techniques are currently providing a unique source of information for identifying some non-nuclear contaminants and tracing their pathways in the environment and, potentially, for investigating their biological effects.

Radiation Applications in Agricultural Production.

The significance of food availability to man is rooted in both our Lord's Prayer as documented in the Bible (Matthew 6: 9–11, *The New American Bible, Catholic Bible Version):*

"Our Father in heaven,
hallowed be your name,
your kingdom come,
your will be done,
on earth as in heaven
Give us today our daily bread…."

and in a popular Yoruba adage which says "Ti ebi ba kuro ninu ise, ise buse" which simply translates as "the pangs of poverty is reduced with a loaf of bread".

Increased food productivity and quality should be a high priority in any country that attaches premium to the living standard of its citizens. Breeding cultivated plants with radiation–induced mutations has resulted in many benefits to agricultural production in many developing countries where the daily consumption of protein is below the minimum requirement. Grain legumes are particularly important in developing countries, providing high protein food at low production cost.

A high yield of crop can be achieved only through a proper combination of variety, environment, agronomic practices, and plant protection measures. Radiation techniques can and have been used to make plant varieties develop resistance to disease and insect attack, thus achieving the best crop output. Through biological interaction, radiation induces genetic alteration in plants, a process generally known as mutation.

Isotopes are ideal tool for studying the behaviour, breakdown and residues of agrochemicals in soil, water, plants, animals and their products.

Radioisotopes are helping in some countries to improve results by:

a) Increasing animals body weight and milk yield through better feeds;
b) Improving breeding of livestock by determining the correct stage of the reproductive cycle through hormone measurements with isotopic methods, and
c) Eliminating diseases by producing vaccines by radiation which are safe and cost effective.

Sterile insect technique (SIT) is a successful way of eradicating pests such as Screwworm, Tsetse flies, Fruit flies, etc by releasing sterile male species to mate unsuccessfully with the females thereby controlling their population. To solve the problem of food surplus, post–harvest loses must be avoided and food irradiation is the best alternative to achieve it. Irradiation of food has a benefit for the reduction of losses through storage. I should like to recall US Congressman, Melvin Price's words (1955):

"I would like to suggest that
we keep in mind what these
developments could mean

for the alleviation of shortages in areas of the world which lack adequate modern transportation and refrigerated facilities"

The electron–and X– and gamma-radiations used to irradiate foods neither induce radioactivity nor transform nuclei. A nuclear technique, which uses a stable isotope as a tracer, helps to determine the best form, timing, and placement of fertilizer to avoid waste and to avoid its movement into the environment.

Medical Applications of Radiation.

But much as we try to protect man from having contact with disease, that unholy 'fellowship' often comes and there comes the task of Medicine. Again, radiation comes handy. In the field of medicine, radiation has been a very valuable tool for the diagnosis and treatment of many human diseases. In diagnostic radiology, electromagnetic spectrum outside the visible light region is used for X-ray imaging including mammography and computed tomography, magnetic resonance imaging and nuclear medicine. Mechanical energy in the form of high-frequency sound waves is used in ultrasound imaging. Nuclear medicine is the branch of radiology in which a chemical or compound containing a radioactive isotope is given to the patient orally, by injection, or by inhalation. Once the compound has distributed itself according to the physiologic status of the patient, a radiation detector is used to make projection images from the X–and/or gamma rays emitted during radioactive decay of the agent.

Body tissue damage or loss especially in developing countries is a major health problem due to the high incidence of accidents and degenerating diseases such as tuberculosis, leprosy, and cancer. Degenerative disease requires the replacement of defective tissue with healthy tissue by reconstructive surgery which leads to an extra wound being borne by the patient with attendant health risks. Also adequate tissue must be found. Cobalt–60 irradiation for sterilization of medical products is used whereby the penetrating radiation sterilizes tissue grafts as used in non – viable tissues such as bone, skin, and nerve material.

Radiation in Warfare.

It is a truth, universally acknowledged, that nuclear weapons are the most destructive weapons invented by man and that their use can imperil all human civilization and the planet on which we live. When a nuclear bomb explodes, unlike a nuclear reactor, there are no neutron–absorbing control rods to moderate its chain nuclear reaction. Therefore, tremendous amount of heat energy is produced.

In 1945, atomic bombs were dropped on two major cities in Japan namely Hiroshima and Nagasaki in an attempt to end the World War II quickly as possible and with reduced loss of lives on the side of the allied forces.

The explosion of the nuclear weapons on these cities produced tremendous physical and chemical effects that mankind never anticipated. This culminated in untold varying biological damages whose management continue to cost trillions of dollars. Since then no limited nuclear war has occurred as the bombing of Hiroshima and Nagasaki used the entire nuclear arsenal of the time. Decades after, serious birth defects are recorded, which are traced to the effect of the act of 1945. No one anticipated that the arms stockpile would escalate to about 10^4 Mt and remain unused for five decades.

The words of Albert Eintein, uttered 60 years ago:

> "The unleashed power of the atom has changed everything except our way of thinking"

remain true today.

My Contributions.

This invaluable instrument of man, called **radiation,** is colourless, odourless (I suppose you now know why I chose to work on it) and invisible; hence it is **the invisible tool** to meet the various desires of mankind, either for beneficial– or destructive purposes. For a more effective use of this powerful tool, its characteristic properties must be accurately investigated to meet the requirements of the users. And this has formed the basis of my active engagements in research and teaching as discussed below:

The Overseas Experience.

Apart from the regular hospital visits during which physicists undergoing training in medical physics are exposed to, the limitless clinical applications of the concepts and methods of physics in the diagnosis and therapy of human diseases, such trainees are also introduced to research work. I had the singular opportunity of working on a project titled:

"Theoretical evaluation of the radioactivity induced in patients undergoing high energy (33–MeV) Radiotherapy".

The 33–MeV photons are produced by electron bombardment of a thick target in a betatron. Two types of interactions are capable of occurring. The electrons can either interact with electrons of the target or with nuclei. The later interactions lead to the production of radiation known as bremsstralung. These 33–MeV bremsstralung photons cause the induction of activity of the isotopic elements of the tissue materials through the various likely photonuclear reactions that could occur. These induced activities increase the dose to an irradiated volume of the tissue. On a number of treatment occasions, the induced activity is a case of unwanted contribution to the dosage to the patient.

However a good study of the radioactivity induced in soft tissues is of radiotherapeutic importance in a number of ways. It provides ideas about the biological changes or damage that has occurred due to irradiation. It is well known that the dose deposited in any material (biological) results partly from ionization losses which affect the electron shells around the atoms and can definitely destroy chemical bonds, and partly due to the nuclear interactions which modify the nature of atoms. Increasing the energy of the incident radiation (electrons) these nuclear interactions gain in number and importance and, hence, account for an increasing fraction of the dose received. The radioactive nuclei produced as a result of photonuclear reactions could best be measured by making use of the induced activity of some appropriate or convenient radionuclides produced in the irradiated volume of the soft tissue of the patient and with an accurate knowledge of total activation cross sections can calculate the total number of reactions that has taken place. These procedures have three advantages:

(a) They are useful for physical dosimetric purposes.

(b) They provide a means for assessing the biological damage done especially to normal cells.

(c) They are tremendously helpful in tumor localization and hence provide adequate knowledge of elemental concentration "in-vivo" of the tumours.

Furthermore, an accurate knowledge of the radioactivity induced in tissues by photonuclear reactions can also provide a singular means to assess the dose received by a person involved in irradiation accident if the person has not worn any personal monitors.

In case where such personnel monitor were worn, the induced activity measurement could be used to investigate the uniformity or otherwise of the dose distribution over the body and if required, the average dose could be determined by measuring, for example, the blood activity.

In November, 1976, I reported, as a new postgraduate student, at the office of the Director of the University of London Reactor Centre (now Imperial College (IC) Reactor Centre) at Silwood Park, near Ascot in England. His Secretary immediately directed me to see Prof. T. D. MacMahon (then Dr. T. D. MacMahon) who took me round the nuclear establishment. The reactor is an enriched uranium/light water system normally operating at a thermal power of 100 kW. History has it that the highly enriched fuel research reactor was designed, constructed, commissioned and operated by first-class rated engineers and scientists who were staff of IC.

The ongoing research topics then were quite many and varied and they included low energy nuclear physics involving neutron capture gamma-ray measurements, decay scheme studies,

evaluation and intercomparison of measurements organised by the International Atomic Energy Agency (IAEA) and the International Committee for Radionuclide Metrology (ICRM) and the reactor physics programme included research activities in development and calibration of fast neutron metrology and spectrometry techniques of nuclear data for reactor design. Other novel research fields included radiation dosimetry, neutron activation analysis (NAA), biological and medical investigations of the role of trace elements in relation to various human diseases, environmental impact assessment of radionuclides released from nuclear power stations and nuclear fuel processing plants, fire assay for the Platinum group metals using NAA as well as nuclear safeguards and nuclear waste management– a research conducted in conjunction with United Kingdom Atomic Energy Authority and the EURATOM in Ispra. I thoroughly went through all the research fields so as to make a valued decision. The mood of the planners of nuclear programmes at UNIFE got through my interactions with the then Vice–Chancellor, Professor Ojetunji Aboyade (now late) and the then visionary Acting Head of Physics Department, Dr. A. F. Oluwole (as he then was) was for trainees to get sound training in pure and applied nuclear physics, accelerator physics, reactor physics, material science, solid state physics, nuclear engineering, nuclear geochemistry, etc but the issue of nuclear safety and radiation protection let alone medical and health physics never crossed their minds. In order not to lose the trend of my academic interest which I have so much fallen in love with, I decided that it would be better to draw up a research project making use of the existing research facilities at the IC Reactor Centre.

I explained to Prof. MacMahon my problem of wanting to keep to pursuing research into the health-related issues of radiation in particular and safety of nuclear technology in general as well as meeting the desired objectives of my sponsor for the Ph.D programme. Prof. MacMahon – a brilliant scholar with an incissive mind then told me that I could be given some days to interact with the various research groups in the Reactor Centre to enable me write a research proposal of my choice. I gladly took this apt and timely advice, I wrote a research proposal which principally involved nuclear fuel investigation and calibration of spectrometers. The facilities to be used for my research project were located in the research group under the leadership of Prof. MacMahon. He gladly accepted to supervise my work. It was also very challenging for me as I was the first postgraduate student from an Africa country to train at the Reactor Centre. It is difficult, if not impossible, to conduct any meaningful investigation into the nuclear properties and management of nuclear fuel and fuel assemblies whether fresh or burnt without a thorough knowledge of certain nuclear data which are of indispensable significance in the investigation of nuclear fuel burnup, neutron dosimetry, and nuclear material safeguards.

Nuclear Fuel Investigation.

Radioactive gamma-emitting fission product nuclides provide a relatively simple but precise way in which the burnup in nuclear fuel specimens can be measured non-destructively (Taylor, 1973). They can also assist considerably, in the measurement of burnup distribution and rating. Several different non-destructive analysis techniques have been suggested,

investigated, and used for the determination of burnup of which gamma-ray scanning of irradiated fuel (Diggle and Blackadder, 1965) is the most widely used. The principal advantage of non-destructive assay, especially gamma scanning, is to provide a quick technique for the measurement of relative burnup or fission. Burnup can be defined simply as atom percent fission which is the ratio of the number of fission to the initial number of total heavy element atoms times 100.

The number of fission in the sample under study can be determined from the activity of a particular fission product present at the end of the irradiation, if the irradiation history of the sample is known. Through the work of Diggle and Blackadder (1965) it is known that well-resolved gamma rays from medium– and long-lived fission product nuclides are often suitable for use as burnup monitor lines. The high resolution germanium detector has enabled the measurement of activity of gamma-emitting fission product nuclides to be carried out with much greater ease and precision when their activities in fuel element are known. It is then possible not only to determine the total burnup but also to understand the irradiation history.

Before formulating the requirements of precision and accuracy in terms of absolute gamma-ray emission probabilities and, hence, measurement of burnup, it is considered of interest to identify the uses to which the final result will be put. Burnup data are used for the measurement of the integrated individual sources of fissions and the total number of fissions, determination of the fission rate both integrated and terminal, and for the energy released per volume of fuel. Its uses also include decay heat calculations as related to nuclear safety considerations, fuel temperature correlation with fuel melting and fission gas retention, studies of waste management, calculation of residual fuel content and reactivity, shielding, coolant requirements, and transportation reactivity. Other uses include calibration of non-destructive burnup analysis techniques, verification of nuclear physics reactor prediction codes, contractual agreements for fissionable and fissile element content in the reprocessing of fuel and estimation of radiolysis and solvent damage in fuel processing facilities.

Another vital field of application of the fission product decay scheme data is in reactor neutron dosimetry performed in research and power reactors. From a knowledge of reactor neutron dosimetry useful information on neutron flux densities, fluence values and neutron spectra can be obtained, an information considered to be of primary type from which, secondary information can be derived relative to fission rates, burnup, damage rates in the fuel and structural materials, heating rates, transmutation rates, helium production and other factors crucial to reactor operation and safety. Another problem is the question of nuclear material safeguards. The need for direct physical methods of detecting, identifying, and quantitatively analysing fissionable materials is a necessary prerequisite for the successful implementation of an effective programme and for nuclear material safeguards and material management. Non-destructive assay methods are among the large variety of techniques employed for nuclear safeguards and are usually divided into two main categories: passive gamma-ray assay and active interogation. Passive (gamma-ray) assay involves observation of gamma-rays emitted following alpha decay (as in Uranium–235 used as fuel for thermal reactors and Plutonium–239 used for breeder ones) which are uniquely characteristic of the individual fissile isotopes,

while active interogation employs an external source of highly penetrating neutrons or photons to induce characteristic nuclear reactions, usually fissions, in the nuclear material which is contained in the sample under investigation. The passive gamma-ray assay method is extremely attractive since it is inherently simple and substantial progress has been made since the introduction of high resolution germanium detectors.

For a precise investigation of nuclear fuel burnup, neutron dosimetry and nuclear materials safeguards, gamma-emission rate probabilities of nuclear fuel monitor nuclides must be precisely known. And this important nuclear data also form the basis of accurate determination of the activity of an irradiated sample and, hence, physical half-life value of any radionuclide. These nuclear decay data are also precisely needed for any radionuclide to be employed to follow a nuclear medicine procedure. Maeck in 1978 gave a comprehensive review of the fission product nuclear data (FPND) requirements for the precise investigation of irradiated nuclear fuel which included the needs and accuracy requirements for FPND important to the fields of burnup analysis, neutron dosimetry and nuclear material safeguards. It was becoming increasingly evident that for many applications in nuclear energy production and distribution, measurements of burnup and neutron dosimetry are required to an accuracy of 1–2% while for nuclear material safeguards accuracy, requirements are in the range of 2–5% for breeder reactors and it is somewhat less for light water reactors. The implication for this accuracy requirements is that crucial nuclear data constants such as gamma-ray emission probabilities for major gamma-rays of fission product monitor nuclide used to establish the number of fissions through fission yields and also physical half-life values of the fission product must be known at an accuracy level required to satisfy the users' needs.

Gamma spectrometry has come into standard use as an invaluable tool for the analysis of radionuclide mixtures, for the study of decay schemes and for activity measurements for other application in medicine, industry and agriculture. It is, however, a relative method and can only be profitably used if the function relating efficiency and energy is accurately known. Therefore, for a gamma detector to be well-calibrated it is absolutely essential that:

➢ the energies of the gamma rays available for use as calibration standards be known with comparable accuracy,
➢ its efficiency has to be accurately determined using reference sources emitting a known number of gamma photons per unit time.

Fast efficiency calibrations can be performed by using sources of radionuclides emitting gamma radiation with different energies spread over the region of interest. Several nuclides have been suggested in the literature and among such multi–gamma sources are Barium–140 and Lanthanum–140 with energies from 109–3118 keV as well as some of the major gamma-rays of Cerium–144 and Prasydomium–144 such as 134, 697 and 2186 keV can also be employed for the efficiency calibration of gamma detectors, most especially germanium spectrometers. The fission product pairs, Cerium–144/Prasydomium–144 and Barium–140/Lanthanum–140 are also suitable nuclear fuel monitor nuclides for investigating irradiated nuclear fuel. Absolute gamma-ray emission probabilities, may be determined in two ways. First method is an indirect one whereby absolute gamma-

ray emission probability is obtained from relative data by an evaluation making use of decay scheme parameters such as beta-ray branching ratios and conversion electron coefficients. The second technique allows direct determination of absolute gamma-ray emission probabilities by measuring the gamma-ray spectrum of an absolutely calibrated source by means of a calibrated spectrometer. The former procedure suffers from major setback as it can hardly be applied for radionuclides with complex decay schemes that involve strong beta branches to the ground states of the daughter nuclides as it is the case with Cerium–144/Prasydomiun–144. I employed the latter method which was performed in two major steps, namely:

* measurement of absolute disintegration rate of the radionuclide source under investigation using a high precision beta-gamma coincidence system of four pi geometry, and
* measurement of the gamma-ray emission rate by means of a germanium spectrometer whose efficiency has been accurately determined for as many gamma-energies as possible using different sets of well-calibrated gamma-ray standards.

This was a novel technique of determining absolute gamma-ray emission probabilities. It was considered necessary to test the accuracy and precision for the direct determination of absolute gamma-ray emission probability for this study with the investigation of the decay of Scandium–46. The merits of the choice of Scandium–46 are three, namely:

▪ Scandium–46 decays through strong gamma–rays following beta transitions to the ground-state of the daughter product.

- The beta-end point energy of 357 keV of Scandium-46 is very similar in value to the Cerium–144 beta-energy of 316 keV.
- Scandium–46 is a very useful tracer of tremendous applications as can be found in the labelling of cement grout which has been used successfully as aids for the construction of North Sea oil platforms in Great Britain and so could be applied in the offshore petroleum exploration in Nigeria as well.

The total disintegration rates of five scandium–46 sources were determined with a precision of 0.3% several times over a period greater than one half–life using four pi beta gamma system .The Scandium–46 half-life was determined for each source from least-squares analysis of the decay curve to yield a new half-life value of 83.79 ± 0.06 d (Olomo and MacMahon 1980) which was documented as the most precise half-life value of Scandium–46 by the report of a Coordinated Research Project sponsored by the IAEA, 11 years after it was published. This data was also circulated to all users of nuclear data by the IAEA in 1991.

Having confirmed the ingenuity of our new direct measurement technique, another radionuclide of great significance, Cerium–144 which decays to its daughter product, Prasydonium–144 was studied. Considerable interest attaches to the decay of Cerium–144. It plays a vital role in nuclear fuel analysis as already highlighted above. It is also used in brachytherapy, as an effective radiotherapeutics for the treatment of superficial lesions especially benign conditions including selected cases of naevi in infants, mycoisis fungoides and various diseases of the eye by means of its 3–MeV beta-ray transition to the ground state of Prasydonium–144.

Furthermore, the uncertainties in the experimental values of the emission probabilities of the monitor lines of Cerium–144/Prasydomium–144 were quite high, about 3–15% while published data were very few for various monitor gamma lines, so new measurements had to be made at the required accuracy of 1% (Olomo and MacMahon, 1981). The half-life of Cerium–144 was also determined using the four pi beta-gamma detector to fundamentally determine the activity of the radionuclide sources, irradiated in the IC Reactor, by accurate absolute measurements over a period of about one half-life. Half-life value is one of the pertinent nuclear decay data widely used in the estimation of photon energy deposition in human organs and tissues (Kim, 1974, White and Fitzgerald, 1975). The use of precise half-life value of Cerium–144 when used as a beta-ray applicator, helps to ascertain that while maximum beta dose is delivered to the superficial tumour, the absorbed gamma dose to the healthy tissues around the tumour is kept as low as reasonably achievable. This work produced 24.893 ± 0.008 d as a new precise mean value of half-life of Cerium–144 (Olomo, 1986).

Barium–140/Lathanum–140 is another fission product pair whose prominent gamma–rays have been widely used in the investigation of irradiated nuclear fuel. Derbertin *et al* (1977) have drawn attention to certain problems which arise when using the 1596–keV line of Lanthanum–140 as a monitor line of fission rate determinations and have concluded that the 537–keV line of Barium–140 is much more suitable for such purposes but scanty and inaccurate data for absolute gamma-ray emission probabilities exist for 537–keV line. So in view of the importance of Barium–140 as a fission rate monitor and the discrepancies in earlier data, it was fell necessary to carry out a new precise measurement of its emission probabilities.

But absolute disintegration rate measurements of the sources of Barium–140/Lanthanum–140 carried out over a period covering several half-lives revealed the presence of a long-lived impurity, making a direct determination of the Barium–140 disintegration rate unreliable. To overcome this difficulty, similar thin sources of Lanthanum–140 were prepared and irradiated in the IC Reactor. The impurities of these sources were confirmed by gamma-ray spectroscopy and by determining the source decay rate as a function of time over several half-lives. These studies yielded a new precise value of the Lanthanum–140 half-life value of 40.295 ± 0.005 h (Olomo and MacMahon, 1980). The disintegration rates of Lanthanum–140 in the mixed Barium–140/Lanthanum–140 were then determined by comparison of their 1596–keV emission rates with those of the pure Lanthanum sources using a high-precision germanium detector. From these evaluations, accurate values of emission rates for the important monitor lines of Barium–140 and Lanthanum–140 were made. (Olomo and MacMahon, 1984).

I had a brief stint, from October to December, 1979, as a Visiting Lecturer at IC Reactor Centre during which I was employed to plan an experiment on decay scheme data for Uranium–239 and Europium–154. Uranium–239 is the most important of the Actinide isotopes responsible for short–term decay heat production at the beginning of irradiated fuel handling and storage. An experiment was, therefore, carried out to determine the major beta branching ratios in the decay of Uranium–239, a conversion reaction product, by comparing gamma spectra from Uranium–239 beta decay and Americium–

243 alpha decay which both populate levels in Neptunium–239 (Holloway *et. al.*, 1983).

In 1978, a "Table of Isotopes" (Lederer and Shirley) quoted two widely differing values of the Europium–152 half-life – 8.5 ± 0.5 y and 16 y. We saw the essential need to resolve this discrepancy and so a long–term experiment was started at the IC Reactor Centre in which the Europium–154 half-life was being measured relative to that of Cobalt–60. An interim evaluation of the data accumulated over a period of 4 years led to a very interesting result yielding a half-life of 9.19 ± 0.24 y (Holloway *et al.*, 1983).

The Ife Contribution.

Though I got two lucrative unsolicited jobs after the successful completion of my Ph. D programme at IC, I returned to Nigeria to take up appointment in the service of UNIFE now OAU in December, 1979 for two main reasons.

The first motivating reason was to serve my three–year sponsorship bond with the University, while the second reason and a very crucial one for that matter was to come home to be part of the first team of trained scientists to execute the nuclear project. I am happy to inform you that this is the first inaugural lecture from that group of scientists that returned home to answer the clarion call. From my frequent interaction with Professor A. F. Oluwole (then Dr. Oluwole) while on graduate training in Great Britain, I had an idea of the Ife nuclear programme plan which involved setting up a nuclear research establishment around some radiation sources such as neutron generator, particle accelerator, gamma irradiator, nuclear fission research reactor and for state–

of–the–art research equipment to be purchased to set up modern research laboratories. From late 1970s to early 1980s two types of neutron generators, namely (a) an open exhaust 14–MeV neutron generator, model 1254 and (b) a sealed–tube 14–MeV neutron generator, model A711 had been paid for with the type (a) above supplied but not commissioned let alone operational. The 9–MV Tandem accelerator had been ordered too from High Voltage in USA. In short, there was no suitable infrastructure in place for me to continue with my research on the safety of nuclear electrical energy production and use as there was no research reactor in place but, Prof. Oluwole later assembled a powerful multidisciplinary team to recommend not only the type of research reactor to be purchased, but also to write the various research projects to set up.

Being the first to return home with a Ph.D degree among those recruited for overseas training for the nuclear programme in 1976, I was really eager to get down to work inspite of the limitations I met on ground. While this arrangement was in progress, I was going back to my laboratory at IC Reactor Centre at my own expense during summer breaks to continue the work on the projects I had set up before returning home in December, 1979 and to use research facilities there for new experiments.

I also started to look inwards by developing a pertinent research proposal aimed at ensuring the nuclear safety and radiation protection of the environment of the OAU which plays host to two nuclear research laboratories, namely the Centre for Energy Research and Development (CERD) approved by the Federal Government of Nigeria (FGN) since 1976 as a Centre of Excellence for Research and Development into peaceful uses of nuclear energy and the Neutron Generator Laboratory located in

the Department of Physics (DOP). I wrote a research proposal on the investigation of environmental radiation. It is essential to operate the nuclear facilities proposed for the OAU such that any person born in the OAU community would not suffer from any hazardous effect (if such a person decided to live all his/her life in the OAU environment.)

The IAEA Board of Governors in 1984 approved the publication of Code of Practice on the safe operations of Research Reactors and Critical Assemblies. The provisions of the code apply to the whole life of the reactor, including modification, updating and upgrading. In a way, the code is aimed at defining minimum requirements for the safe operation of reactors. So any Government which wishes to enter into an agreement with the IAEA concerning the design, construction, operation, experimental use, decommissioning or safety evaluation of a reactor will be asked to follow the recommendations in the code.

When a nuclear site is chosen, it is very imperative for the management of such a site to plan the operation of the nuclear facilities to meet the requirements of the 1984 IAEA Code of Practice. A major part of the Code is Safety Report. There is a chapter of the Safety Report known as Site Characteristics which is required to provide information on the geological, seismological, hydrological and meteorological characteristics of the site and vicinity in conjuction with present and projected population distribution, land use, site activities and planning controls. Other vital information needed for a comprehensive documentation of the Site Characteristics include Baseline Radiological Levels (BRL). An accurate knowledge of the initial or reference radiological background of a nuclear site is essentially useful for the following purposes:

- To assess the impact of a nuclear station on its environment, it is necessary to have baseline data against which subsequent operation can be judged.
- Following identification of a site, a preoperational survey establishes the background levels of radioactivity and radiation.

One of the after–effects of the Three Mile Island (TMI–2) nuclear accident in USA on 28th March, 1979 and the worst civil nuclear accident at Chernobyl–4, in Ukrane on 26th April, 1986 has been the imposition of supplementary sampling system to those operating under normal conditions so that a plant is also capable of performing accident condition analysis.

In 1988, I set up a research project on environmental radiation monitoring of radionuclides in food and environmental samples in response to:

(i) the unauthorised toxic waste dump at Koko seaport in 1988. The Koko Waste was first taken as a radioactive waste which definitely would have brought serious hazardous effects on the inhabitants and its environment.

(ii) compliance with international safety requirements for the safe operation of nuclear facilities for peaceful purposes as there was no nuclear– and, or, radiological regulatory law in Nigeria then.

The objectives for such environmental radiation monitoring also cover other technical as well as social/political reasons as outlined below:

- **Public Reassurance and information.**
  In order to arrest increased public concern, results of environmental monitoring will ensure openness of information and give the doubting public the reassurance it seeks that activity levels are in all cases trivial and not measurably different from natural background levels.
- **Management of Nuclear and Radiological Emergencies.**
  In the event of an emergency, routine surveillance programmes provide basis for the extensive monitoring that would be needed. Additionally, and perhaps most important, they provide a large data base of the pre-emergency situation and, hence, allow accurate assessment of where environmental changes have taken place.
- **Contribution to Research.**
  Environmental monitoring data will provide some insight into the behaviour of radionuclides in the environment, particularly if discharges albeit within authorized value, are detected in the environment, it can be useful to extend the monitoring programme to provide research data on how a specific isotope behaves.
- **Assessment of the Radiation Exposure of the Public.**
  The impracticality of direct monitoring of the radiation exposure of the public is a prime reason for monitoring the environment for radioactivity. The environmental monitoring data, together with

habit data of the population concerned, can provide an indirect means of assessing radiation exposure of the local inhabitants.

For a quick response to the challenges posed by the aforesaid Koko Waste Dump in 1988, some seven popular Nigerian foodstuffs were sampled from places of radioprotection significance in south west region of Nigeria. Radionuclides that accumulate in foods and drinking water constitute a direct route of exposure to human population when the contaminated foods and drinking water are consumed. Thus, internal exposure of humans to ionising radiation from the ingestion of food and drinking water has been noted with great concern (Simpson *et al.*, 1981; Stroube *et, al*, 1985, NCRP, 1975). The food samples were studied by the non–destructive gamma spectrometry. The radionuclides identified with reliable regularity in all the food composites studied were the naturally occurring types headed by Uranium–238 and Thorium–232 in addition to the non–series type, Potassium–40. (Olomo, 1990). The mean specific activity concentrations recorded for Uranium–238 and Thorium–232 were quite low but high for Potasium–40, giving a high dose to humans consuming such foodstuffs but because Potasium–40 is an essential biological element and its concentration in human tissue is under close metabolic (homeostatic) control, variations of Potasium–40 in dietary composition do not influence significantly the radiation dose received.

Similarly work was done in early 1960s on environmental radiation monitoring after a nuclear weapon was reportedly tested in the Sahara Desert which is close to the northern boundary of the country. This led to the establishment of FRPS in 1964 at the DOP of University of Ibadan (Agu, 1994) but only the air

medium was monitored on the roof of FRPS building. Other later works involved investigation of gamma–ray background in Jos area in Plateau State and assessment of the contamination levels due to uncontrolled dumping of tailings from tin ore processing (Ńwosu and Sanni, 1974; Babalola, 1984).

The specific objectives of the comprehensive environmental radiation monitoring programme set up at OAU include the following:

(i) To undertake precise measurements of outdoor gamma exposure rate in the environment of the nuclear research facilities at the Obafemi Awolowo University, Ile-Ife.

(ii) To determine the concentrations of the natural radionuclides in foodstuffs and various environmental fields, which constitute immediate pathways leading to the contamination of foods. Such pathways include soil, surface and drinking water, vegetation and sediment, obtained from the vicinity of the nuclear research facilities at the OAU, Ile-Ife.

Some nuclear research facilities which have varying capacities to increase the level of ionising radiation in their immediate physical environment were being installed at both CERD and DOP, while some were already operational. Such facilities include a 9–MV van de Graaf Tandem accelerator and a sealed tube neutron generator, model A 711 while at the DOP, a pumped–type neutron generator, model 1254, had just been installed. In addition to these radiation sources, a self–contained dry gamma–

source Cobalt–60 irradiator with initial activity strength of 888 TBq and a X-ray theorescence (XRF) unit were also installed. It was well documented by Raph and Graham (1988) that, when operational, the 9–MV particle accelerator has tendency for serious radiological impact on its immediate environment, the workers and the general public due to many exposure pathways which consist of radionuclides and noxious chemical such as O_3, NO, etc in the air of the accelerator vault and their subsequent release to the environment; long-lived radionuclides in accelerator components that may be subsequently recycled with their consequent transmission into the general environment, etc.

Furthermore, there are two other centres approved by the FGN to actively engage in planning research and development of nuclear technology in Nigeria including sound training of nuclear technology personnel. These include the Centre for Energy Research and Training (CERT) located in the Campus of Ahmadu Bello University (ABU) and Sheda Science and Technology Complex (SHESTCO), Federal Capital Territory. CERT was to acquire a 1–kW research reactor for radioisotope production and training purposes while SHESTCO, established by the Decree 43 of 30th August, 1991 was initially designed to contain a Nuclear Technology Centre (NTC) made up of special laboratories to be equipped with nuclear research facilities such as a multi-purpose 30 MW research reactor, a cyclotron, 37–TBq Cobalt–60 gamma irradiator, nuclear fuel fabrication plant, critical assembly plants, etc.

All the above enumerated nuclear facilities when operational have tendencies to release radioactive effluents to their immediate environment during normal and at a higher level in emergency situations. Besides all these, a quick look at the

map of Africa shows that Nigeria is surrounded by several countries which host operational and yet–to–be critical nuclear (research or power) reactors. Figure 3 illustrates the countries in Africa having nuclear (research or power) reactors.

In our unique approach to evaluating the radiation burden of the OAU inhabitants, the following pathways of practical interest in nuclear Site monitoring were considered:

(a) External Irradiation:
- (i) Source to Man,
- (ii) Source to Water to Man,
- (iii) Source to Water to Sediments to Man,
- (iv) Source to Air to Man,
- (v) Source to Air to Soil to Man.

(b) Internal Irradiation:
- (i) Source to Water to Man
- (ii) Source to Water to Fish to Man,
- (iii) Source to Water to Soil to Food to Man,
- (iv) Source to Air to Man,
- (v) Source to Air to (Soil to) Vegetation to Man
- (vi) Source to Air to (Soil to) Vegetation to Meat or Milk to Man.

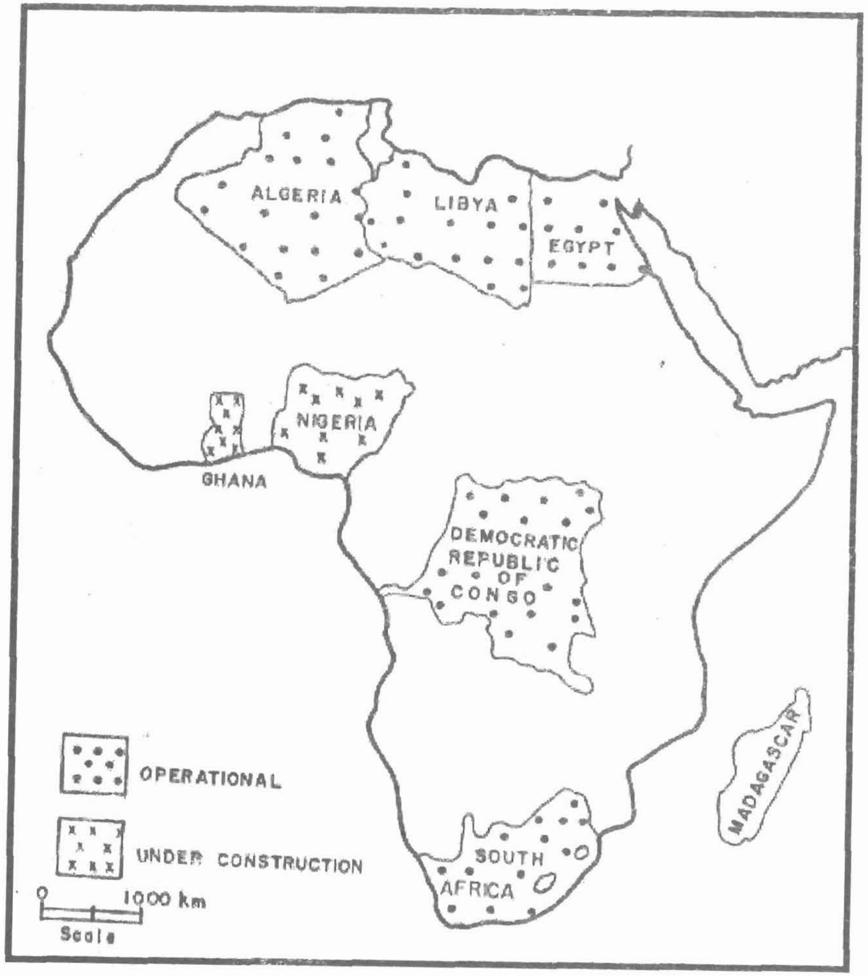

Fig 3. Map of Africa showing Countries with Nuclear Reactors

With the above pathways of radiation to man, thirteen sampling locations of radioprotection significance were identified as can be observed on Figure 3, four of which are agricultural farm lands and one is the main source of water supply to the community as well as to some parts of the Ile–Ife township. Dose to man was the quantity of interest of our work so sampling locations were near

populated areas as well as source of food and water supply to the population. The radionuclide concentrations of the soils and surface and drinking water were studied (Olomo *et al.,* 1994), the gamma radiation exposure rates 1 metre above the air–ground interface were accurately determined using thermoluminescent dosimeters (Akinloye and Olomo, 1995) and the meat and poultry consumption contribution to the natural radionuclide intake of the inhabitants of the OAU community was also precisely investigated (Akinloye *et al.,* 1999) including accurate determination of the radionuclide concentrations of the food composites from a variety of tubers grown in agricultural farm lands within the OAU environment. These included Gari, Cassava Flour, Pounded Yam and Yam Flour respectively (Akinloye and Olomo, 2000). The Opa dam not only serves as water source for the OAU community, it also hosts a fish research project from which fish are harvested and sold to members of the OAU community as well as interested members of the public. The sediments and four species of fish were investigated for radionuclide content (Akinloye and Olomo, 2002).

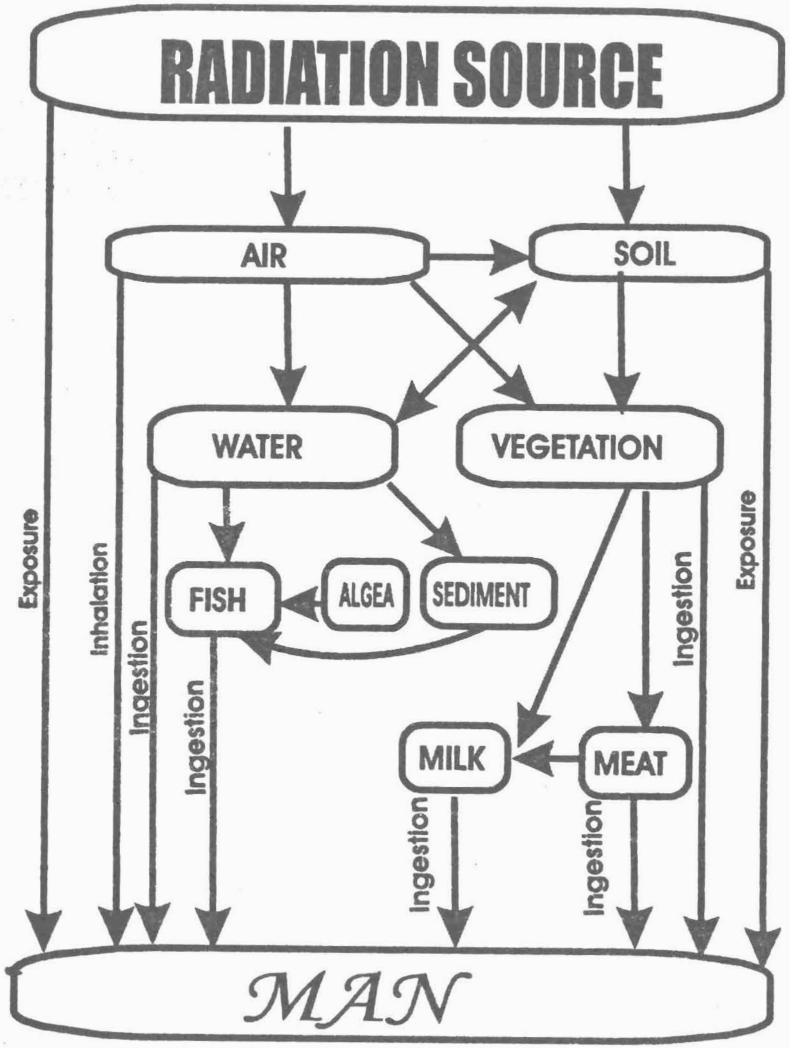

Fig 4. Pathways of Radiation contamination to Man

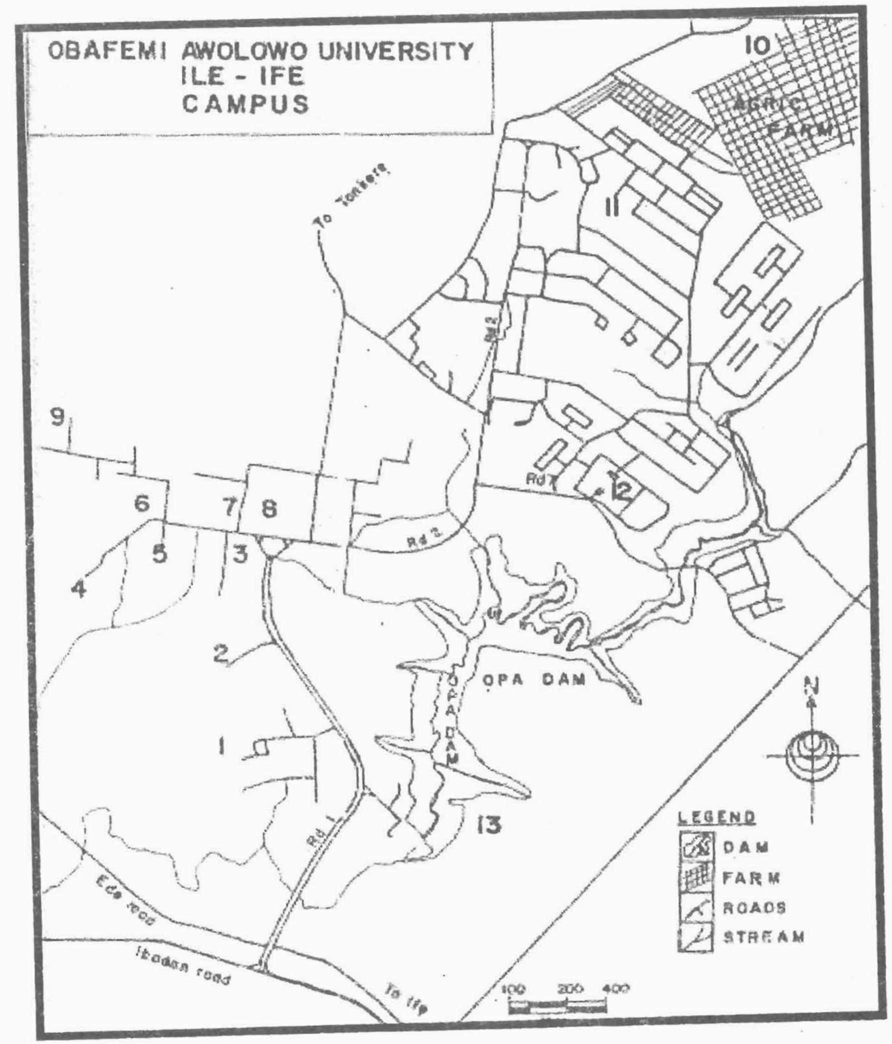

Fig 5. Map of OAU showing sampling Locations

S/N	Sampling Location
1	CENTRE FOR ENERGY RESEARCH & DEVELOPMENT
2	RELIGIOUS CENTRE
3	STUDENTS' UNION BUILDING
4	NEW BUKATERIAL
5	FAJUYI HALL
6	HEALTH CENTRE
7	DEPARTMENT OF PHYSICS
8	ODUDUWA HALL
9	COMMERCIAL FARM
10	TEACHING AND RESEARCH FARM
11	ROAD 20B IN OAU STAFF QUARTERS
12	ROAD 7B IN OAU STAFF QUARTERS
13	OPA DAM

Table1. Sampling Locations for Environmental Radiation Measurement

In 1996, the world marked the tenth anniversary of the Chernobyl–4 nuclear power accident with various conferences, workshops and seminars. I designed a research project to monitor the radionuclides in some milk samples widely distributed and consumed milk products all over Nigeria. Nine different milk samples which were imported from some European countries were analysed using well–calibrated high purity germanium detector system. The radionuclides reliably observed did not include any of the long–lived fission products as could be

observed from the gamma-ray spectra of various milk samples contrary to the work reported by Farai (1993). Another reason why no comparison could be made between the results of Farai and our work (Osibote *et al.*, 1999) was not only because the food composites in Farai's work were distintfully different (milk products and infant milk) but food identies were not made known as they were coded. The radionuclides observed were those of naturally occurring series radionuclides of Uranium–238 and Thorium–232 and their progenies. The other type belongs to a non–series radionuclide, Potasium–40. Potassium–40 recorded the highest mean value of concentrations followed by Radium–226, a progeny of Uranium–238, while Radium–228 recorded the least concentrations and hence the least dose to consumers of these milk products. The results of our work, no doubt, justified the positive effects of some countermeasures reported by Richards and Hance (1996).

We investigated the radiation burden of a population of about 100,000 people in two nearby local governments, namely: the Ife–Central and Ife–East Local Governments by measuring the mean radionuclide concentrations in water samples collected from reservoir, streams, borehole, deep and shallow wells, water pipes, etc being the most frequently used water sources in the study area. Thirteen sampling locations were selected on the basis of population density, institutions, farm settlements, and the highly polluted ones containing intolerable levels of contaminants which may also include radionuclides from conventional non–nuclear industrial sources. The radionuclide concentrations obtained from this study (Tchokossa et al., 1999) were relatively low but further measurements are required so as to be able to get a good data that could assist the National Agency for Food and Drug

Administration and Control (NAFDAC) to recommend a standard for radionuclides in water.

The National Policy on Environment aims to provide a rational, practicable, coherent and comprehensive approach to the pursuit of economic and social development in a way that minimizes contradictions and duplications, while enhancing inter-- and intra – sectoral cooperation and effectiveness at all levels. Contaminants from human activities pass into the air, into the soil and water, and, hence, into the fish, crops and other animals (UNEP/GEMS, 1992). The input of Potassium–40 to the environment is derived from soil and atmospheric diffusion (Myttenaere, et al., 1993; Papp *et al.*, 2002).

The radiological study of Oil and Gas producing areas in Delta State was undertaken bearing in mind that the best documented but perhaps still unappreciated input of enhanced natural radioactivity is from fossil, namely oil and gas. Their radioactivity results from the significant content of uranium, thorium, radium, radon, and polonium isotopes which are enhanced and then released during fuel extraction and burning. Oil and gas burning is characterized by interesting interactions with natural decay series nuclides, particularly, with the radium and radon isotopes. Thus, for example, radon-222 diffuses into natural gas and oil deposits within the earth and its daughter nuclides are subsequently released in the power plants or dwellings where the fuels are burned. It has been estimated that the critical group near a gas-fired power plant can receive an effective dose equivalent of up to 20 micro-sieverts per year through ingestion of radon-222 progeny in seafoods and leafy vegetables. A similar dose contribution can result from radon-222 inhalation in homes burning natural gas.

Oil and Gas sector has continued to be the backbone of the Nigerian economy, contributing about 90% of the nation's foreign exchange earnings and about 25% of the

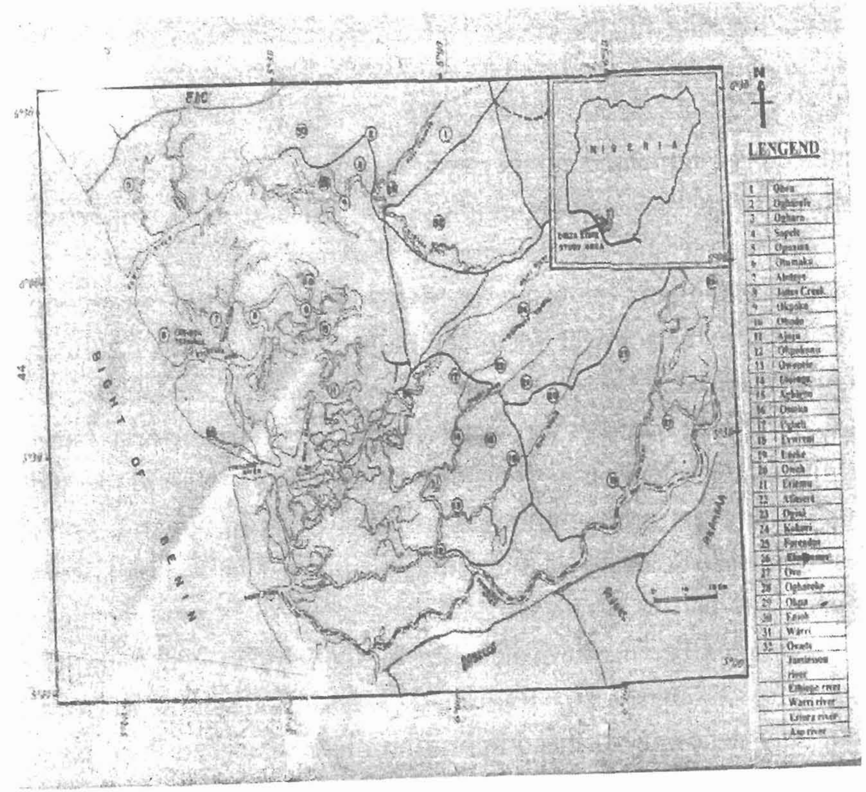

Fig 6. Samples Location of Oil & Gas in Delta State

GDP. The sustainable development of Oil and Gas Sector is, therefore, of utmost importance especially since virtually all of the activities in both the upstream and downstream sub-sectors are not only pollution-prone, but readily provoke social discord (FEPA, 1999). Their exploitation has brought serious environmental degradation and health impact on the communities from where they were produced. Delta State happens to be numbered amongst them. In addition to the naturally occurring radionuclides produced as explained above, radioisotopes, especially neutron–emitting ones, are majorly employed in oil and gas prospecting and drilling. Thus, we determined the presence and levels of radionuclide, assess the effect of resulting dose on the population and evaluate the transfer factor of radionuclides through various sample matrices.

Varying samples of water (well, taps, stream and rain), soil, sediments, terrestrial food and aquatic foods were collected from oil and gas producing areas of Delta State in Nigeria. Forty locations were selected as sampling locations. The samples were prepared as earlier discussed and measured on highly sensitive well calibrated germanium detector system. Mean concentration values for Radium–226, Radium-228 and Potassium–40 were accurately determined. In addition, the mean absorbed dose rates and the mean annual effective dose for Radium-226, Radium-228 and Potassium-40 were precisely determined. The study (Tchokossa, 2005) really confirmed the presence of those radionuclides in the matrices examined from this area.

Furthermore, mean transfer factor for Radium–226, Radium–228 and Potassium–40 for all the matrices studied were determined. Interestingly though, man-made radionuclide such as

Cessium-137 was identified in soil samples in eleven out of seventeen sampling locations and its concentrations, absorbed dose, annual effective dose and mean transfer factors to the matrices studied were made for a region of the country that serves as its jewel of inestimable value. Overall, the total absorbed dose rate at 1.0 m above the ground was low (ICRP, 1991). Transfer factor was relatively higher for Potassium-40 than for other radionuclides- Radium-226, Radium-228 and Cessium-137, detected in all the samples analysed.

The effects of radioactivity in building materials and other environmental sources of radiation exposure of the public throughout the world have been of great concern especially now in developing countries where the planning and managements of rural and urban dwellings pose daunting challenge, the major problem being lack of guidelines governing the use of building materials and the consequential radiation burden of the public (Eikelboom *et al.*, 2001). Olomo and his co-workers in 2003 measured the radioactivity content of a variety of local and imported construction materials commonly used for the construction of dwellings in urban areas in four States of the South-west region of Nigeria. Large samples of the most important and commonly used building materials were identified and collected from the production lines of several factories, building construction sites, quarries, and sand and gravel digging sites located in towns and villages covering four states, namely Ondo, Ogun, Lagos and Osun. Our sampling which covers final products for building as well as primary and intermediate products used for the production of building materials, followed a systematic approach using the published work of Oshin and Rahman (1986) on uranium favourability study in Nigeria.

The sampling locations covered both low and high background radiation areas as survey meters with scintillation and pancake probes were used as indicators of radiation levels in the sampling areas. Large samples of the various building materials, such as, gravels, cement, sand burnt bricks, roofing asbestos, and ceiling asbestos were collected and taken to the Radionuclide Meteorology Laboratory in the CERD of OAU, Ile-Ife. for spectrometry analysis.

The photopeaks observed with regularity in the sample were identified to belong to the naturally occurring series decay radionuclides headed by Uranium–238 and Thorium– 232 as well as a non-series natural radionuclide, Potassium–40. Their activity concentrations were measured indirectly by means of gamma rays emitted by their respective daughter nuclides. Other radionuclides if present appeared rather infrequently at low levels or occurred at levels below the minimum detectable limits (MDL) statistically determined at two-standard deviation analytical error.

There are three principal ways by which the human body can be contaminated by radioactive materials and radiation and these include ingestion, inhalation and through an open wound. In furtherance of our work on environmental radiation monitoring in food and the environment, we undertook the study of radionuclide concentrations in palm oil produced in Ogun State University (OSU), (now known as Olabisi Onabanjo University (OOU)) Oil Mill in Ago–Iwoye, Ogun State.

The study of radionuclides concentration in palm oil is of a great radioprotection significance in view of the wide uses of palm oil for domestic and industrial purposes by people of various age and sex and, hence, the need to establish ~~minimum~~ concentration levels of radionuclide in an important food

composite such as the palm oil produced at OSU Oil Mill which is consumed by people not only in Nigeria but also in some neighbouring countries in the West African subregion. Radionuclide concentrations in both the bottom and top layers of the palm oil were measured. Large samples of top and bottom layers of palm oil were collected a day after production from the palm oil processing plant. About one litter of each of the palm oil samples was accurately measured into a clean 1-L Marinelli beaker and was well sealed for 28 days to avoid escape of radon gas which, if not prevented, will disallow the attainment of a state of radioactive secular equilibrium. Four samples were prepared from each layer of palm oil analysed.

The total uncertainty in the measured concentrations is estimated to be of the order of 25% due to the combined uncertainties in the homogeneity of the samples (the top oil is thinner and has lower viscosity while bottom oil is thicker and has higher viscosity), their position with respect to the detector, the calibration procedure, the peak area determination and the background correction.

Exposure of humans to ionising radiations has its corresponding detriment depending on the dose level. We studied the outdoor gamma-exposure rates in some metropolitan and industrial cities located in the south-west region of Nigeria in order to generate valuable data for evaluating possible health hazards to the inhabitants in the study area.

The study area covers seven States (Lagos, Ogun, Oyo, Osun, Ondo. Ekiti and Kwara) located in the south-west region of Nigeria with sampling locations in metropolitan and industrial cities, namely Ile-Ife, Ibadan, Abeokuta, Ota, Lagos Ikorodu, Sagamu, Ilorin, Osogbo, Akure, Ado-Ekiti, Ijebu-Ode, Ago-

Iwoye, Ikare and Ondo, were selected as the sampling locations. In each city, two sampling locations were identified giving a total of thirty sampling locations. These including hospitals where there are multitudes of people either as patients, patients' visitors and hospital personnel for almost 24 hr of a day; residential and recreational areas, institutional areas which host several people daily, industrial areas which release their effluents in the form of gas or liquid to the immediate environment or in the form of gas plume into the cloud and later through turbulence in the atmosphere. The radioactive effluents get diffused into the environment and through external irradiation, and man could be endangered.

Radiation exposure rate was carried out using TLD phosphor, Calcium Sulphate activated with dysprosium (CaSO4: Dy), while measurement technique was similar to earlier work (Olomo and Akinloye, 1995). Exposure rates recorded varied sharply over a short range of distance particularly in industrial and metropolitan areas. UNSCEAR in 1988 reported that an area has a normal background radiation if its natural radiation absorbed dose in air is from 30–70 nGy h^{-1}. Thus, the mean exposure rate for the area studied fall into this classification.

Paints have found numerous uses in Nigeria and all over the world both domestically and industrially. Such uses include painting of buildings used for residence, office, hospital, workshop, auditorium, institution for people of varying age and sex, etc. It is also used for spraying vehicles, such as cars, lorries, ships, aircrafts, etc. The furniture we use in our homes, offices and other public places also benefits from paints by its beauty. Thus, radioactivity contents of paints are of great corcern in radiation protection. But radioactivity content data on paints are scanty and

mostly of poor accuracy. Hence, the necessity for the work we carried out on some paints available in Nigeria.

Five different types of liquid paints commonly used by Nigerians were collected both from factories, departmental stores and from construction sites and prepared for gamma spectroscopy. Mean concentrations of the paints were determined at two standard deviation analytical error. These mean concentrations for Radium–226, Radium–228 and Potassium–40 which were the radionuclides identified with reliable regularity were accurately determined. Radium–226 and Radium–228 concentrations recorded for these paints agreed with those found in literature, while those for Potassium–40 are generally less than other published works. Thus, their uses would not lead to increased radiation burden of the users.

Accurate radiation dosimetric data are very essential to the optimal industrial, agricultural, medical and environmental applications of ionising radiation. In this area of research, I have contributed to accurate estimation of the radiation energy deposited in living and non-living matter using light-emitting property of some irradiated solids (mannose). In a published paper (Balogun *et al*, 1994), we showed for the first time that grain-size bands affect lyoluminescence (LL) yield, sensitivity and reproducibility of dose calibration curve and that increased probability of oxygen diffusion is the cause of increased LL yield for large grain-sized phosphor. This information has found use in the radiation dosimetric technique for personnel and environmental dosimetry which is a major contribution to a better understanding of the description of the properties of ionising radiations.

Development of Nuclear Safety and Radiation Protection Programmes.

(a) Medical– and Health Physics Graduate Programmes.

Immediately I took up an appointment with UNIFE now OAU in December, 1979, I started to make plans to design a postgraduate degree programme in Medical– and Health Physics in order to build a formidable army of physicists to work in Specialist and, or, Teaching Hospitals and in either Nuclear Energy Establishments or in a Nuclear Regulatory Body whenever the Federal Government of Nigeria decided to set one up.

At the end of course work, trainees are exposed to some clinical physics training through hospital visits and projects. The postgraduate degree programme is available at both M. Sc and Ph.D levels. The field of Medical Physics overlaps the two very large fields of medicine and physics. Medical physics is the application of the methods and concepts of physics to the function of the human body in health and disease leading to a better understanding and practice of medicine. Health Physics deals principally with the restriction of ionising radiations to useful areas thereby avoiding situations that could make workers and members of the public to be unnecessarily exposed.

The course was designed to give a wide coverage of the whole field of medical– and health physics to good honours graduates in physics, engineering physics, or a closely associated discipline and thus provide a foundation for a career in Hospital Physics, Bio-medical Physics research or medically oriented industry.

After perfecting the design of the graduate programme, I took it for open discussion at an apt International Conference with the theme "Applications of Physics to Medicine and Biology" organised by the International Centre for Theoretical Physics (ICTP) (now known as the Abdus Salam International Centre for Theoretical Physics), Trieste, Italy from 30th March – 3rd April, 1982. After I orally presented our proposed graduate programme, many useful issues were raised and answers to them proferred.

During the lunch time on the second day of the conference, someone just beckoned to me as I was looking for a place to sit in the cafetaria. I responded and the person told me he too had the type of my native attire. I jokingly asked him if I could share a table with him and he promptly agreed. I then introduced myself and where I came from. He simply introduced himself as Abdus Salam. I asked him if he was the same as the Director of ICTP. I could not hold back the volcanic eruption of joy in me. I also told him of my IC training where he was a Professor of Physics and a Nobel Laureate. After all these I let him into our proposed postgraduate training in Medical– and Health Physics Programme. Prof. Abdus Salam, was really a Servant of Peace who devoted his life to Principle of Unity of Nature and of Mankind. His great wisdom, his analytical mind and humility were to me one of the glories of ICTP.

The M.Sc degree option of the graduate programme in Medical– and Health Physics took off with one student in October, 1982 under my supervision. That student today who also started work in the Department of Physics as a Graduate Assistant is now a Reader in Medical Physics. Few years ago the postgraduate programme was reviewed and expanded into two separate programmes namely Medical Physics and Health Physics and the Environment. These programmes have continued to attract brilliant students from within and outside Nigeria.

In August, 1982, the then ICTP organised a 4–week College on Biophysics and I was also invited to participate. During the course of this College, Professor Abdul Salam had audience with me in the presence of the Biophysics College Director, Prof Sergio Mascarenhas from Brazil. Professor A. Salam was happy to know that our Postgraduate Training in Medical– and Health Physics would take off in October, 1982. He then asked Prof. Mascarenhas to write a proposal for a Medical Physics Workshop that would involve lectures and practicals for young promising academics.

I was awarded a Junior Associate of the ICTP for 6 Six years in December, 1982. I also was invited in November, 1983 to the First Medical Physics Workshop with Professor J. R. Cameron – an Icon of Medical Physics, as one of the Resource Persons. I gained tremendously from interacting with these international faculties and this had helped the rapid development of our postgraduate programme in Medical– and Health Physics.

(b) Nuclear Safety and Radiation Protection Law.

In November, 1987, this Inaugural Lecturer who was then leading the Nigerian Association of Medical Physicists (NAMP) as its president learnt about a gigantic nuclear programme being planned by the then Federal Military Government under the supervision of the Federal Ministry of Science and Technology without the involvement of a trained

Medical / Health Physics experts. Under the auspices of the professional body, NAMP, I wrote to warn and adequately advised the FGN on:

(i) the need to put in place a functional regulatory law for a thorough and efficient management of the design, construction, commissioning, operation and decommissioning of nuclear facilities and their products. The law would constitute an exacting and rigorous safety policy which will not only be an obligation to our own citizens, but also a duty towards the international community.

(ii) the need to involve Medical– or, at least, Health Physicist in the planning of the said nuclear programme.

This is because radiation does not respect local or international boundaries once released into human environment. With the intervention of many stakeholders, a Nuclear Safety Committee was inaugurated to amongst others; draft a law on nuclear safety and radiation protection as well as to do an inventory of all radiation sources users in Nigeria. I headed the subcommittee also made up of NAMP members that produced the draft of the regulatory law. After series of modifications, the said law was passed in January, 1995 but not functional as there was no incorporation of a sufficiently competent and independent nuclear regulatory organization for ensuring protection and safety. It was only a few years ago that such a competent body for the efficient management of the regulatory law known as Nigerian Nuclear Regulatory Agency (NNRA) was created. I am also happy today that SHESTCO is a product of the intellectual debate generated by that letter I wrote to the Minister and copied to the then Military President of the Federal Republic of Nigeria.

(c) **Radiological Physics Course for Resident Doctors in Radiology.**

This Inaugural Lecturer, since October, 1994 has been actively engaged in the meticulous teaching and examining of Radiological Physics to Resident Doctors in Radiology at part I level of the Fellowship Examinations in Radiology of the National Postgraduate Medical College of Nigeria and the West African Postgraduate Medical College of Surgeons. He has also assisted the Radiology Faculties of both the West African Postgraduate Medical College of Surgeons and the National Postgraduate Medical College of Nigeria to review the syllabus for the Radiological Physics with the sole aim of bringing it into the required world standard. Update courses are also organised for Resident Doctors preparing for Fellowship Examinations as the need arises.

Recommendations

Mr Vice Chancellor in the course of my research, I found out that the public fear about nuclear technology is rather unfounded and that, strictly speaking, nuclear safety and radiation and environmental protection must be raised to an acceptable level in Nigeria. To do this, the following well–thoughout suggestions are worth making to improve the safe handling, uses and disposal of radiation sources:

* The Federal Government of Nigeria took the rightful decision for the multi–various steps taken towards solving the problems of energy security of this country through the establishment of the Energy Commission of Nigeria (ECN), the Nigerian Atomic Energy Commission, SHESTCO, NNRA, CERD, CERT, National Agency for Science and Engineering Infrastructure (NASENI), etc. These important and essential establishments, whose functions are directly related to sustainable development of nuclear energy, should be well funded by the FGN for them to meet the timely realisation of their desired objectives.

* If the primary objective of sustainable energy development for Nigerian society is to maximize welfare while maintaining or increasing the stock of income and providing a safety net to meet the basic needs and thereby protect the poor, then, reliable, cheap and clean energy such as nuclear electricity must be developed for Nigerian society as soon as possible. In fact, the time to take that firm decision to go for nuclear electricity and its other peaceful purposes is now that we have a visionary government at the centre.
* The safe planning, development and uses of energy sources, particularly the nuclear electricity, in this country should be properly addressed as early as possible by tapping and taxing, even to the extreme, the ingenuity of the national experts on nuclear safety and radiation protection so that sound and straight–forward answers are developed on the most topical issues on radiation safety as soon as possible.

* The NNRA – the competent body for ensuring radiation safety should be totally independent of the users of ionising radiation and nuclear technology unlike the present arrangement when it is being supervised by the Ministry of Petroleum Resources – the largest user of ionising radiation in Nigeria. This is because the safe exploitation of energy, albeit nuclear energy; is indissolubly linked with the health protection of workers and the general public as well as environmental management.
* The NNRA should set up a national radiation monitoring network to detect and track radioactive plume releases from within or outside of Nigerian boarders. The network will operate continuously and will provide radiation monitoring data from across the country to be assembled and analysed rapidly. This will ensure that Nigerians are kept fully informed of the development and consequences of any nuclear incident or accident overseas.
* Radiation and radioactive materials are serious environmental pollutants which can be harmful for a long period of time. The issue of radioactive waste management should be embarked upon before large scale peaceful uses of nuclear energy are commenced.
* In developed countries, only medical doctors and dental surgeons competent in radiation effects of and protection against ionising radiations are allowed to take responsibility for both diagnostic and therapeutic uses of ionising radiations. Thus, the use of X-rays at a dental practice should hencefort be subject to the

requirements of the Nuclear Safety and Radiation Protection Law of 1995. This will put an end to the current abuses in the use of dental X-rays in Nigeria.
* The NNRA needs to embark on massive recruitment of scientists from universities and research institutions who will be given intensive traning in the country and in atomic energy establishments abroad for proper management of uses of nuclear technology for peaceful purposes.
* The relevant regulatory authorities, namely: NAFDAC, Standard Organisation of Nigeria (SON) and NNRA should work jointly on how to monitor radionuclide concentrations in foodstuffs, building materials, miscellaneous items, etc, being imported into the country to ensure that they do not contain enhanced radioactivity and hence increased dosage to users and to the public at large.
* The FGN should set up a powerful team made up of nuclear and other related scientists as well as sound economists to critically look at Nuclear Science Research and Development with the purpose to draw up a 21st Century Development Policy to be backed up with good funding for its timely realisation.

Conclusion.

In the course of this inaugural lecture, I have laboured with you to illuminate our thoughts on the inspiring positive role of radiation as the door and the key to a sustainable development that could usher in a better standard of living for all humans by taping and taxing its limitless applications in energy, agriculture, medicine, industry, environment, teaching and research, etc. I have also highlighted my contributions in improving our understanding of characteristics of radiation through accurate nuclear decay data.

The reported serious cases of nuclear accidents (TMI–2 and Chernobyl–4) which were mainly caused by human violation of established safety procedures have taxed human ingenuity to tremendously improve on the safety of nuclear technology for peaceful purposes.

Prof Dennis Anderson, an expert on energy matters and an erudite professor at IC London, whose Research and Development Team has a lot of influence on British Government thinking about innovation and energy policy once said:

> "Looking back to the 1950s there were fears that Coal and Oil were running out, and it was an era of incredible smogs. Pit disasters were common and mining was arduous and unhealthy. Nuclear energy seemed to provide the answers".

He concluded by saying:

> "It is enormously important to involve developing countries in the task of developing and demonstrating the new energy technologies – if only because the cost per unit of energy produced are five times lower than in the UK and their energy needs are so large".

Mr Vice Chancellor, distinguished audience, ladies and gentlemen, I strongly believe that we should not agree less with Professor Anderson. I also consider nuclear science research to be a public good, with enormous positive externalities for the public and business as well as for future generations. In a developing economy like that of Nigeria, this deserves more encouragement by a visionary government and not less, through impressive funding. I am very grateful to God for blessing my untiring efforts at developing Medical Physics as well as Nuclear Safety and Radiation Protection, over these years. Today, in reputable Nigerian Universities, I have about five of my students who are now colleagues in the professorial bracket, while some of those that I taught in Engineering Physics degree programme since December, 1979 are doing very well in academic establishments overseas.

Furthermore, I have served the nation through some national assignments such as Chairman of Technical Advisory Committee set up by NNRA to produce Licensing Guide Document for Gamma Irradiation Facilities (GIF) in Nigeria. Also, I have served meritoriously as a Principal Radiation Safety Consultant to Ladoke Akintola University of Technology, Ogbomoso to safely set up its diagnostic X-ray system.

I deeply thank you all for listening.

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