ATOMIC ENERGY:
THE MYTH AND THE TRUTH

An inaugural lecture delivered at the University of Ibadan

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By

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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Registrar, Librarian, Provost College of Medicine, Dean of Faculty of Science, Dean of Postgraduate School, Dean of other Faculties, and of Students, Directors of Institutes, Distinguished Ladies and Gentlemen.

Introduction

It is a great honour for me to stand here today to give this inaugural lecture on behalf of my faculty, the Faculty of Science. It happens to be the last in the series of our University inaugural lecture series for the 2010/2011 academic session. One of the foremost Nigerian mathematicians, Professor Adegoke Olubunmo (1922 – 1992), was asked, twenty one years after he became a professor, to give his inaugural and valedictory lectures within an interval of two weeks. Realizing how incongruous it would be to separate the beginning and the end with such an infinitesimally small time interval, he opted for the valedictory lecture which was the more apt as he was just a couple of months to retirement. He titled the valedictory lecture, "What does it all add up to?" ($\sum = ?$), and gave in a brilliant prose, a summary of the travails of a typical academic at that time.

Reflecting now on the matter, I think it was a big loss to this University that this erudite professor did not have the opportunity to tell us his exploits in the abstract world of functional and harmonic analysis, his primary field of research. The university community was similarly denied of the opportunity of listening to one or two of my senior colleagues in the Department of Physics, and many more in my faculty and other faculties. The queue was just too long that it was never their turn before they retired. I therefore consider it phenomenal that I am giving my inaugural lecture today, barely five years after the professorial chair. I thank the immediate past Dean of Science, Prof. K.O. Adebowale most sincerely for giving me the slot. Permit me also to quickly, on behalf of all the other beneficiaries of the new order, thank the University authorities for the very thoughtful step taken to increase the frequency of inaugural lectures. Hopefully, the backlogs would soon be cleared.

From Nsukka to Ibadan

As far back as thirty-two years ago, when I graduated from the University of Nigeria, Nsukka (UNN), a B.Sc degree in Physics was one of the university degrees commonly referred to as 'single honours'. The popular belief was, and unfortunately still is, that holders of such degrees were condemned to the impoverished world of teaching. My first impulse on graduation was therefore to avoid like a plaque, the teaching profession. Together with Dapo Giwa, a close friend and a fellow Physics graduate who was as desperate as I was to avoid the teaching career, we submitted four sets of application forms and visited Marina Lagos over ten times in our bid to join the Federal Ministry of Works as pupil land surveyors. The application forms were either declared not found or said to be receiving attention. In my desperation and perhaps because of my physical built, I considered joining the Nigerian Army but my mother asked me, in her characteristic bluntness, to wait until she died. I was truly in limbo for the first two years after my NYSC even though I was then an assistant lecturer in the Physics Department of the Polytechnic Ibadan.

In those days (may be up till now) in the Ibadan Polytechnic, there were regular and well publicized seminars in the various departments. When it was my turn to give a seminar, Professors Awele Maduemezia and Lateef Hussain from Physics Department, University of Ibadan (UI) were in attendance. Meeting these eminent Physicists for the first time in my seminar was quite intimidating. I presented my final-year project on Band Gap Studies of Semiconductors, at the seminar. In the project, I used a simple diffraction grating to split white light into its wavelength components and measured the electrical conductivity of CdS as a function of the wavelength of the light irradiated on it. Based on Plank's principle, I obtained an energy band gap of 2.32 eV for this semiconductor compared with the published value of 2.42 eV (Farai 1979).

At the end of my presentation, I was praying very hard that neither of the two guests would ask me any question, but Professor Maduemezia calmly asked what my plan was for the future. I wish I could tell him about my application forms in the Federal Ministry of Works, but I simply answered that I was not quite sure of anything in particular. He asked me to see him in UI for a chat, a request to which the other guest nodded in agreement. It was after that chat with him that I resolved, come rain or shine, to accept my rendezvous with academics. I was employed as a Graduate Assistant along with three other young graduates in this great University in November 1982, less than three months after the seminar. This was under the headship of Professor (now Emeritus Professor) Olumuyiwa Awe. When I now sum up everything, the good, the bad, the ugly and the ordinary that life has been in the last three decades, I think I have every reason to say in the words of Joe Cocker in one of his popular songs, *I am so glad I am standing here today!*

My Choice of Research Area

The physical universe is sustained by interactions between matter and energy. Albert Einstein expressed his opposition to the idea of chance in the interaction processes by saying, "God does not play dice". There are laws which govern every interaction process. Physics is the study of these laws, often through empirical measurements and/or with the language of Mathematics. The Department of Physics was established as one of the foundation Departments of this University in 1948. As far as back as in the early fifties, the Department had been involved in active postgraduate research activities. One of the first PhD degrees awarded by this University was from this Department in 1955 to one Dr. A.R. Brown in the area of Ionospheric Physics.

By the time I joined the Department, the six areas of active research were Theoretical Physics, Solid Earth Physics, Condensed Matter Physics, Ionospheric Physics, Atmospheric Physics, and Radiation and Health Physics. There was at least one cogent reason for me to join any one of four of the six groups. My successful B.Sc project that brought me to limelight is in the area of Condensed Matter Physics. Professor Maduemezia that was so instrumental to my coming to the Department is in Theoretical Physics. Professor A.I.I. Ette, a great teacher and a mentor who had so much confidence in me is in Atmospheric Physics where, like Sango priests, they celebrate each lightning and thunder event. I pitched my tent with the Radiation and Health Physics group. This is a branch of Atomic and Nuclear Physics, my fantasy as an undergraduate student.

Physics as a discipline needs teachers, not lecturers and from my experience, pedagogical skills go with the teacher's passion for the subject. The two teachers who taught me the fundamentals of atomic and nuclear physics in UNN succeeded in inculcating in me their passion for the subject. One of them was an Irish nun, Professor Margaret Heeran, who to me was far more dedicated to teaching than to the convent. The other was Professor Frank Ndili, a 1961 alumnus of Ibadan, who later became the Vice-Chancellor of UNN. These two great teachers simplified the subject of atomic physics without losing its substance and made my interest far stronger in this area than in any other area of Physics. They remain my role models in the teaching profession.

Radiation and Health Physics Research at Ibadan

Radiation and Health Physics is a branch of physics which deals with the protection of man and the environment against the harmful effects of both ionizing and non-ionizing radiations. It involves both scientific and engineering aspects of measurement of the different types of atomic and nuclear radiations, establishment of quantitative relationships between radiation exposure and the resulting biological damage, movement of radioactivity within the environment and the design, use and monitoring of radiologically safe radiation emitting equipment and facilities. It may interest us to know that radiation emitting equipment and facilities range from the remote control and TV set at home, to the radiotherapy unit in the hospital, nuclear power installation generating Mega Watts of electricity (MWe), and of course to the nuclear warhead, the use of all of which the modern man has found most inevitable. The natural environment itself in some regions and under certain anthropogenic conditions can pose radiation health hazards. The Radiation and Health Physics group in Ibadan is the pioneering group in Nigeria. Those in this field in other Nigerian universities and research centres have their roots in Ibadan. We owe this leadership role and our modest achievements largely to the existence of the now defunct Federal Radiation Protection Service (FRPS) in the Department.

Following nuclear weapon tests in the Sahara desert in the early sixties, the Nigerian Meteorological Services set up six sample collecting stations at Kano, Sokoto, Maiduguri, Kaduna, Port Harcourt and Ikeja. The environmental samples collected from these stations were sent to the United Kingdom for the determination of the radioactive content. In the attempt of the newly independent government to be self-reliant on this matter, the Federal Radiation Protection Service (FRPS) was established in the Department of Physics, UI, in 1963 under the aegis of the Federal Ministry of Health through an act of parliament. It was charged with the prime role of keeping surveillance on the Nigerian environment. With the commitment of the few nuclear scientists in the Physics Department then, the unit was able to live up to this responsibility (Agu 1965 and Sanni 1972). Over the years, the use of ionizing radiation in medicine, industry and research in Nigeria increased, and the FRPS had to add such duties as personnel dosimetry, facility inspection, research and training, to its initial role.

The other body that we benefited a lot from is the International Atomic Energy Agency (IAEA), Vienna, Austria, which was established in 1957 as a world body to stop the proliferation of nuclear weapons with the attendant rampant nuclear testings in the 1950s. It was also to serve as the world's foremost institution to promote and support the aspirations of individual member states to harness atomic energy for peaceful purposes. Nigeria joined the IAEA in 1964, about the time the FRPS was established. The FRPS gained tremendously through the various national projects on radiation protection, which were well funded by the IAEA. The funding was mainly through capacity building by ways of fellowships and expert missions as well as through supply of equipment. The unit was thereby able to acquire essential equipment in radiation protection which have been quite useful not only for the FRPS to meet its national and international responsibilities, but also for the Radiation and Health Physics group to carry out academic research. I am a proud beneficiary of these opportunities. My relationship with the FRPS tallied with a Yoruba adage which says that, "while you take care of the sick; you must take care of yourself too"!

Many members of this community see the neighbourhood of the FRPS facility as a nuclear zone and a possible threat to the environment. This is a myth which I must use the opportunity of this lecture to correct. The truth is that for more than 25 years, my colleagues and I have kept watch over this environment, first with Thermoluminescent Dosimetry (TLD) technique (Farai 1984), and subsequently with combinations of different techniques. It is well established that research activities within and around the FRPS over the years have not resulted in any radioactive pollution of the environment. The FRPS has since 2006 metamorphosed into the National Institute for Radiation Protection and Research (NIRPR), an arm of the Nigerian Nuclear Regulatory Authority (NNRA), Abuja. The Department of Physics has continued to enjoy a robust relationship with the institute through a Memorandum of

Understanding (MoU) between the University and the NNRA. The current Director of the institute, Prof. F. A. Balogun, has been particularly enthusiastic and cooperative in our teaching and research efforts in the Department. Regular area monitoring of the facility has become a routine exercise and more so now that the magnitude of use of radioactive sources has increased in the centre.

Physics of the Atom

The word atom was derived from the Greek word *atomos* which means indivisible, after the atomic theory proposed by a Greek philosopher, Leucippus (450 BC) and formally put forward by John Dalton (1808), which described the atom as that which could not be subdivided. Today, we know that atoms are not indivisible but made of smaller particles: *protons, neutrons and electrons*. We in fact now have many High Energy Physics centres such as the Stanford Linear Accelerator Centre (SLAC) in California, USA, which is a two-mile straight line underground particle accelerator, built in 1962 to accelerate protons to billions of electron-volts (GeV). The protons are used to probe matter beyond the proton and the neutron. Over two hundred elementary particles or ***quarks***, many with life times less than 10^{-6} s, have been discovered. More are still being discovered.

An American Physicist and a Nobel laureate, Richard Feynman (1918 – 1988) once said, *"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, the statement that would contain the most information in the fewest words is that ...* ***all things are made of atoms.****"* The universe is maintained by the energy resulting from the interactions between and within atoms. Radiations come from the atom and the fact that radiation affects man is because all things; both living and nonliving are made of atoms. Mankind has invested many centuries (450 BC to present day) of rigorous efforts to unravel the nature of atoms.

Our current understanding of the atomic and subatomic particles stemmed from a major revolution which shook the world of Physics at the turn of the 20^{th} century. The arrowheads of this revolution were some thirty uncommon human species who ruled the world of science in the first half of the twentieth century. Among them were fifteen Nobel Prize winners in Physics and three in Chemistry. Lord J. J. Thompson (in 1897) discovered the electron and established that it carries the basic unit of electricity (1.6×10^{-19} C). Ernest Rutherford (in 1911) through his famous α-scattering experiment established that an atom has a positively charged nucleus, which contained most of the mass of the atom and which is surrounded by electrons. Niels Bohr (in 1913) postulated that the electrons are held in distinct orbits by the electromagnetic force between the nucleus and the electron, very similar to how gravity holds the moon in orbit around the earth. The angular momentum of an electron in an allowed orbit is defined by $mvr = \frac{nh}{2\pi}$, which successfully predicts the spectral lines from the hydrogen atom.

A more accurate model of the atom which predicts the properties of all atoms is given by the quantum theory. Max Plank (in 1900) introduced the idea of quantization of energy ($E = h\upsilon$) which successfully explained radiation from a blackbody. To explain the photoelectric effect, Albert Einstein (in 1905) extended Plank's work and established that at certain instances, light (electromagnetic) waves behave like particles or energy packets called photons. Louis de Broglie (in 1923) postulated the converse of Einstein's dual nature of light. That is, under certain situations, a material particle such as an electron with momentum p, behaves like a wave with wavelength $\lambda = h/p$, where h is plank's constant (6.6×10^{-34} Js). This would appear to violate common reasoning because we know a wave to be a spread-out disturbance without mass, which is distinctly different from a material particle that has a mass and located at a definite point in space. The sense in the postulates of quantum theory is however, in the accuracy of its predictions. After all, our sensibility is defined by the limits of our experience.

If a particle behaves like a wave, it must have associated with it a wave function $\psi(x,y,z,t)$ with which we can determine its position, momentum and energy at any time in space and its total energy will be the sum of its potential and kinetic energies. Based on this, Schrodinger (in 1926) proposed his famous wave equation for a particle of mass m moving in the presence of a potential V(x). The solution of the Schrodinger equation for the simplest atom (hydrogen) is a formidable mathematical problem and has never been a piece of cake for physics students (and their teachers!). It is however of so much fundamental importance in atomic physics that students love to have it now as tattoos as shown in figure 1.

The radial Coulomb's force on the electron due to the nucleus at the centre of the spherical atom gives rise to a spherically symmetric potential. From the space geometry of the problem (fig. 2), the resulting wave function is of the form: $\boldsymbol{\psi(r,\phi,\theta) = R(r)P(\theta)F(\phi)}$. These three functions give rise to the three quantum numbers n, l and m which respectively, specify the restrictions on the energy of the electron, its angular momentum and its orientation in an external magnetic field. A fourth quantum number s arises from electron spin about its own axis. The four numbers define the state of an electron. Just as no two individuals can be identical in every respect, Pauli's Exclusion Principle (in 1925) states that no two electrons can have an identical set of quantum numbers. This principle sets the limit on the number of electrons which can occupy a given state in an atom.

Fig. 1. A tattoo of time dependent Schrodinger equation.

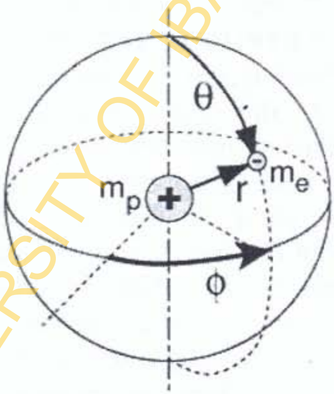

Fig. 2. Space geometry of the atom resulting in $\psi(r,\phi,\theta)$.

Schrodinger equation is a huge success not only for predicting the energy states of electrons in an atom, but also for explaining other quantum mechanical systems. Its success put paid to any doubts about wave-particle duality. A practical application of wave-particle duality was established through the invention (in 1934) of the electron microscope (*magnification* ~ 10^6), which is based on diffraction and interference, two properties that are exclusive to waves. For me, wave-particle duality only reinforces my belief in the holy trinity as expressed in the Apostle's creed. If the electron can manifest as a particle at one instance and as a wave at another instance, who am I to doubt that the Father, the Son and the Holy Ghost are manifestations of the same entity under different situations?

Energy from Orbital Motion

The normal state of an atom is one in which all the electrons are in the lowest possible (ground) energy states and when excited to higher states, they instantly ($t \sim 10^{-6}$ s) return to the ground state with the emission of the difference in energy as electromagnetic radiation ($E = h\upsilon$) whose wavelengths are characteristic of the atom. Electromagnetic radiation types emitted this way include characteristic x-rays, ultra violet (UV) light, visible light, infra red (IR) light, and microwaves. Characteristic x-rays are particularly useful for several reasons. Whenever bound electrons in the inner (K or L) shells are ejected, electrons from higher energy states promptly fill the resulting vacancy. The energy difference is released as an electromagnetic radiation in the x-ray region and it is characteristic of the emitting atom. That is, no two atoms emit the same combination of wavelengths, which makes it possible to identify and quantify different elements in a mixture from the energy and relative intensities of radiation emitted. This is the principle of X-Ray Fluorescence (XRF) and other spectrometric techniques in environmental pollution assessment. Characteristic x-rays from Mo ($Z = 42$) are particularly most suitable for mammography with which healthy women are screened for breast cancer.

Apart from characteristic x-rays produced from orbital transitions, there is the other form of x-rays (*bremstrahlung* x-rays) produced when electrons accelerated by a high potential difference (in kV) are decelerated by the nuclei of a target material. The deceleration results in a conversion of the kinetic energy of the accelerated electrons to electromagnetic energy in the x-ray region. Roentgen (1895) discovered this very penetrating radiation by chance when experimenting on the phenomenon of fluorescence, and called it x-rays because of its unknown nature then. He immediately recognized its power as a medical diagnostic tool, and the first ever radiograph produced was that of his wife's hand (fig. 3).

Today, x-rays are used not only in medical diagnostic radiology, but extensively in industrial non-destructive testing (NDT), and airport, seaport and land border scanning operations. Figure 4 shows scanner pictures of hidden fire-arms at an airport, while figure 5 is that of illegal emigrants concealed in a banana truck across the Mexico-US border.

Fig. 3. The first X-Ray film (1896).

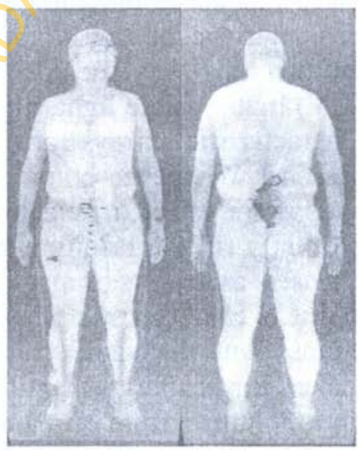

Fig. 4. X-ray images in security service.

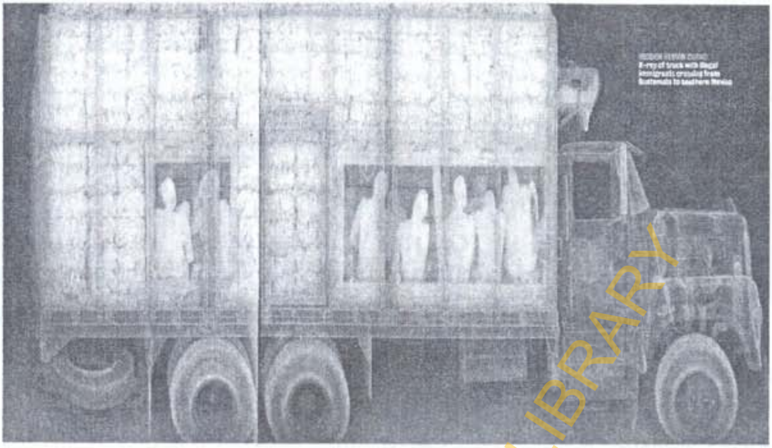

Fig. 5. Cargo scanner image of illegal emigrants in banana trucks.

Energy from the Nucleus

The bulk of atomic energy comes from spontaneous or externally induced activities in the nucleus. With a density of about 10^{17} kg/m^3, the nucleus is the central tiny core of the atom about which the electrons revolve in orbital shells. The nucleus is composed of Z positively charged protons and N neutral neutrons, collectively referred to as nucleons. It may seem contradictory to say Z positively charged protons are packed in the small volume of the nucleus when we know from the popular axiom that: *like charges repel and unlike charges attract*. The protons should fly apart.

The truth is that there are four fundamental forces of interaction in nature; gravitational, electromagnetic, weak, and strong forces. The challenge right from Einstein's time to date has been to get a grand unification of these four basic interactions. We all can recall the well orchestrated God Almighty's Grand Unified Theorem (GAGUT) proposed recently by a Nigerian, Prof. Gabriel Oyibo. It was claimed that GAGUT was the unified interaction which great scientists have spent over a century looking for in futility. In a display of our own brand of patriotism, many Nigerians believed we should have had another Nobel laureate. Please permit me to leave this as a topic for discussion at another forum!

The repulsive electromagnetic force between a pair of protons is well counteracted by the attractive strong (nuclear) force which draws any pair of nucleons together. There is stability for many nuclei as a result of the balance between the two opposing forces. For many other nuclei however, the number of protons in relation to the number of neutrons is such that balance cannot be maintained. Such nuclei become unstable because the binding energy is not enough to keep the nucleons in equilibrium. All stable nuclei fall on the stability line shown in the Segre graph in figure 6. Those outside the line are unstable either because of too many neutrons or too many protons.

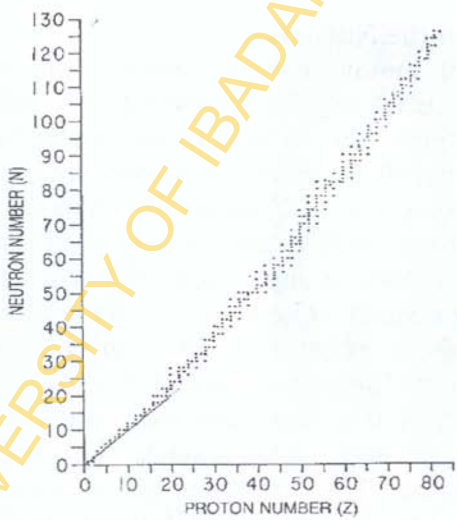

Fig. 6. Segre graph for stable nuclei.

It is a natural tendency for any unstable physical system to seek stability. Contrary to flying apart of protons however, the unstable nucleus seeks stability by undergoing one spontaneous intra-nuclear transformation or the other that shifts the N to Z ratio to a more stable configuration. The primary transformation involves release of disintegration energy and emission of a charged particle (α^{++}, β^{-} or β^{+}) or the capture of an orbital electron by the nucleus to turn a proton to a neutron. For the purpose of this lecture, we can ignore the uncharged neutrinos without rest mass which always accompany and share energy with β particles. The mode of decay and hence the type of accompanying radiation depend on cause of instability, available energy, parity and the different conservation laws. A typical final-year project for my students is the study of the energetics of α-decay from the Weizsaker semi-empirical mass formula based on the liquid-drop model. Popoola (1994) demonstrated with a plot of disintegration energy (Q-value) against atomic Z as shown in figure 7, that α- decay is possible only if Z > 82, bearing in mind that no α- particle with energy less than 4 MeV has been observed.

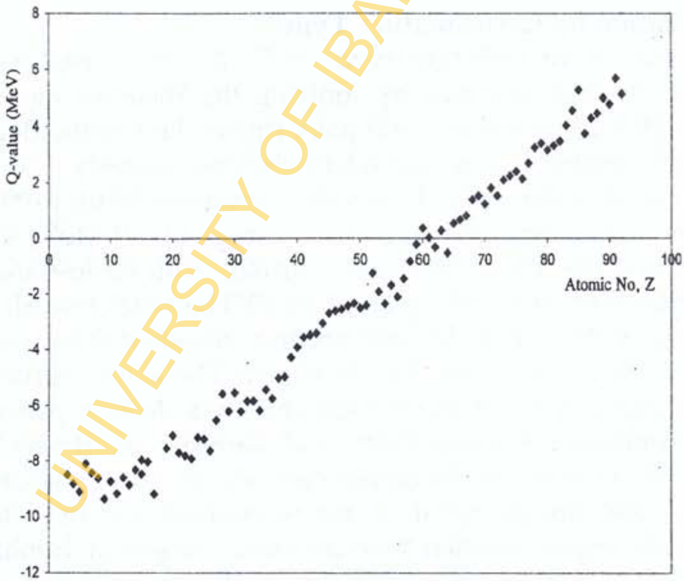

Fig. 7. Disintegration energy Q against atomic number Z for alpha decay.

Each of the transformations results in a product nucleus Y which is chemically different from parent X. The daughter nucleus Y is very often produced in an excited state, which is followed immediately by a de-excitation process resulting in the emission of the extra energy in form of a type of electromagnetic radiation called gamma (γ) radiation which is similar to x-rays. The secondary emission of γ-ray energies is due to energy level transitions in the daughter nucleus which goes to confirm that like electronic shells, there are energy shells within the nucleus. This is well supported by the spin-orbit coupling theory of the nucleus. Because of these radiation emissions (α^{++}, β^-, β^+, *and* γ), the transformations are termed radio-activity or radioactive decay, a phenomenon which was discovered by Becquerel in 1886. Madame Maria Curie (in 1903) got the Nobel Prize for her immense contribution to the subject, particularly the discovery of many natural radioactive elements such as Ra-226.

Ionization by the Radiation Types

All the above radiation types (α^{++}, β^-, β^+, γ *and x-rays*) dissipate their energies by ionizing the medium they pass through leaving ion-electron pairs (ip) in their trails. Because of their double charge and relatively slow velocity (~ 0.05c), α^{++} particles have a high specific ionization of up to 50,000 ip/cm in air. They expend all their energy (4 – 9 MeV) within 4 cm in air or a few μm in solid media. With far less specific ionization of about 500 ip/cm, beta (β^+) particles lose all their energy (0.01 – 2 MeV) and become absorbed within a few meters in air or a few mm in solids. These two particulate radiations can be effectively shielded by a sheet of paper and an aluminum foil respectively, and therefore are of very little concern in external radiation exposure in the environment. They are however, of grave consequences in internal radiation exposure when a radionuclide is ingested or inhaled.

On the other hand, gamma and x-rays are electromagnetic radiations with small specific ionization of 6 – 9 ip/mm in air and hence, are by far more penetrating. Their absorption in a medium depends on their energy and the density of the medium, which explains how bone and tissue would produce contrasting shadows on a radiographic film. It is the ionizing properties of these particulate and electromagnetic radiations and the fact that a radioactive element is chemically indistinguishable from its stable isotopes that give rise to the large variety of applications of radioisotopes in all facets of life. Unfortunately, the same ionizing properties are also responsible for the dreadful detrimental health effects of these nuclear radiations.

Health Effects of Ionizing Radiations

From the very beginning, it was not realized that ionizing radiations have harmful effects that could be avoided if safe practices were implemented. Unfortunately, it was through the lives of those who experimented with radiation as pioneers that the consequences of unprotected use of ionizing radiation were known. Clarence Dally, an assistant radiologist, suffered severe x-ray burns that required amputation of both arms which eventually claimed his life in 1904, making him the first radiation fatality (Joseph Jr. and Phalen 2006). By 1922, it was estimated that more than 100 radiologists had died from occupationally induced cancer (Martin and Harbison 1979).

The basic unit of life, the biological cell, contains more than 70% water and a variety of other compounds. Radiation damage to the human cell and the eventual health effects on the exposed individual are due to physical and chemical changes that result from the ionization and excitation events in water molecules. Ionization of water molecules results in the breakage of bonds in the water molecule leading to dissociation of H_2O to H_2O^+ and e^- pair, and subsequently to production of groups of other ions, free radicals (H and OH), aqueous electrons and compounds like H_2O_2. The energy required to dissociate water is about 16 eV/molecule which sets the limit to the radiation energy that can induce health effects in man. The three important *reactive species* (e_{aq}, OH, and H), with initial relative yields of about 45%, 45%, and 10%, respectively (El Nagar 1988) are short lived and their concentrations at any point depend on the specific ionization of the radiation type. They attack the DNA molecules in the cell resulting in biological damage which can lead to various health effects.

Acute radiation exposure (high radiation dose within a short time) can result in immediate deterministic effects referred to as acute radiation syndromes (ARS) due to bone marrow, gastrointestinal and neuromuscular damage, with possibilities of injury and death depending on the dose. It can also result in delayed deterministic effects like skin burn, infertility and cataract. Acute radiation exposure (dose > 1Sv) occurs only in the very rare cases of accidents due to failure or human bypass of the very tight safety mechanisms in radiation equipment. Chronic exposure to radiation at low levels for a long time can result in stochastic effects like cancers of all forms and genetic effects. The present linear no-threshold (LNT) model is that any level of radiation exposure, such as in taking an x-ray film, has a finite probability of resulting in some stochastic effects (UNSCEAR 1982).

In any radiation application, there are some limits below which exposure and the associated risk are deemed justified from the cost and benefit analysis. This sets the limits for quality assurance. For instance, the acceptable risk for chest x-ray is about 40 cancer cases per million (ICRP 60 1990; Berringhton de Gonzalex and Darby 2004). The risk is cumulative, which makes it important that x-ray pictures are taken only when it is medically prescribed. Our study (an ongoing PhD research) carried out at four diagnostic centres in Ibadan, Ile-Ife and Abuja using a Monte Carlo based technique shows that each chest x-ray taken at one of the centres carries an estimated risk of cancer of as much as 3000 per million. This is unacceptable.

Mr. Vice-Chancellor Sir, it is therefore very true that the advantages of the numerous applications of nuclear radiations are unfortunately accompanied by the disadvantages of radiation health hazards. The popular belief that people must get sick, have cancer, become impotent, infertile and produce malformed offspring whenever radiation is produced or used in an environment is however, not true. This myth was carried to a ridiculous extent in Nigeria some three years ago when there were hues and cries about some belts imported from Japan purposely to irradiate male gonads and render Nigerian men infertile as a means of curbing the rising population figures. The reason for the uproar was that this brand of belt had a magnetic buckle. I wish to inform this enlightened community that radioisotope production and subsequent application involve far more elaborate procedure than that of making a shirt in Aba. There are well structured water-tight radiation protection mechanisms against the harmful effects of ionizing radiation. Production, transportation, storage and use of radioactive materials are subject to very stringent standards derived from thorough cost and benefit analysis imposed by many international organizations such as the IAEA, International Commission for Radiological Protection (ICRP), the World Health Organization (WHO), the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), and many others. No radioactive belt can possibly exist!

Atomic Energy for Health and Wealth

Perhaps because of the history of its development and early use, the popular myth is that nuclear technology is synonymous with nuclear armament, which summons an assortment of dreadful consequences. It is erroneously believed that it is only the very rich and industrialized nations that have the right and the means to join the exclusive nuclear club. The truth however, is that, a country can thrive in health and wealth on the enormous energy of the atom without necessarily having a nuclear power reactor or a nuclear arsenal. Nigeria cannot be said to have embraced nuclear technology, even in its most rudimentary form, which makes the current vision of becoming one of the 20 most industrialized nations in the world by the year 2020 a big joke. Let me point out briefly our low level of performance in nuclear technology.

Radiotherapy

Radiation therapy involves the use of intense gamma radiation from a radioisotope or high energy x-rays from a LINAC machine to kill cancer cells. With a projection of half a million new cases every year by now (Solanke 2000), cancer has assumed prominence as a major cause of mortality in Nigeria. Brachytherapy, which involves surgical implantation of the radioisotope directly on the malignant tissue, was first carried out in Nigeria at UCH in the 1960s. Teletherapy, which is by far more common, involves the radiation source being at some distance (1m) from the patient. This was first carried out in Lagos University Teaching Hospital (LUTH) in 1970. Unfortunately today, over four decades after, only six radiotherapy centers exist in Nigeria for a population of about 140 million. Information on these centres is given in table 1. If we compare this with another developing nation, Argentina, which, 14 years ago had 84 centres for a population of 32 million (IAEA 1997), our performance in this area of modern healthcare delivery is most unacceptable.

Table.1: Information on Radiotherapy Centres in Nigeria

Location	Machine Type	Source	Year of Installation
UCH, Ibadan	Theratron 780C	Co-60	1992
LUTH, Lagos	Theratron 780C	Co-60	1988
LUTH, Lagos	AGAT RI 60	Co-60	1992
EKO Hospital, Lagos	Mobatron 100	Co-60	1998
ABUTH, Zaria	Cirus B	Co-60	2000
National Hospital, Abuja	ELETKA 105500	LINAC	1999

One drawback of radiotherapy is that irradiation of the ailing organ may damage surrounding healthy cells. The main focus is therefore to deliver a precise dose to a well defined area of the body in order to incur minimal damage to healthy tissues. Some studies like ICRU (1974) and Brahme (1984) indicate that an accuracy of less than 5% variation from the prescribed dose must be delivered for a successful treatment. I had the opportunity of an IAEA fellowship in 1997 to visit the Secondary Standard Dosimetry Laboratory (SSDL) facility at the Malaysian Institute of Nuclear Technology Research (MINT) in Kajang, where we investigated calibration procedures for the output of a therapy source. Using an 8.9 TBq Co-60 Teletheraphy machine, Farai and Kadni (2000) demonstrated that an accuracy of 1.4 % was possible with NE 2561, NE 2581, TK and other ionization chambers when IAEA or HPA protocol of calibration is employed. Back home, Farai and Obed (2004) showed that only one of the four centres operating in Nigeria at the time of our survey met the 5% dose precision requirement. The situation was so bad that a centre was closed down for about two years by the NNRA for low quality assurance records following the report of an audit team led by my humble self (Farai et al. 2002).

Gamma Irradiation Facility (GIF)

A GIF is a radiation facility with a high activity ($10^{12} - 10^{18}$ Bq) γ-ray source or a high energy (MeV) X-ray LINAC machine designed for sterilization of medical and pharmaceutical products, preservation of agricultural and food products, polymer synthesis and eradication of insect infestation. The principle of food preservation and hospital equipment sterilization is to kill microorganisms (bacteria) with some specified high dose of gamma radiation and up to date, the success and safety record of the industry worldwide have been quite impressive (Farai 1996). Unfortunately, this is another nuclear technology yet to be embraced by Nigeria despite the annual colossal waste resulting from our inability to preserve food and abundant agricultural products. I was privileged to be a member of the Federal Government team that licensed the only commercial GIF in Nigeria in 2006 (Olomo et al. 2006). This is a 300 kCi (1.11×10^{16} Bq) Co-60 GIF located at Sheda Science and Technology Complex (SHESTCO), Abuja. It has been operating now for about five years but most regrettably, the targeted clients in the agricultural, industrial and medical sectors as well as researchers are yet to take full advantage of its existence.

The popular myth about this nuclear technique is that goods (especially food items) taken through the gamma irradiation preservation process become radioactive and hence, hazardous thereafter. Unfortunately, the same myth surrounds microwave heating of food items. This opinion is as incorrect as saying that an item will start emitting sun rays after drying it in the sun! The truth is that the radiation from GIF only kills microorganisms in the material leaving both its quality and wholesomeness and molecular structures 100% intact. Although the mechanism of matter-energy interaction is different from that of GIF, if properly used, microwave heating does not change the quality of food item any more than conventional cooking does. We must also know that, irrespective of whatever we think in Nigeria, the rest of the world has embraced this technology and our consumption of items preserved or sterilized by gamma irradiation technique is inescapable. We are only losing by not taking full advantage of our own system.

Radioisotope Production

The naturally occurring radioisotopes are grossly inadequate for the various applications of radioactive materials. Over 95% of the radioisotopes used today are obtained through nuclear reactions of the form X(x,y)Y. That is, a suitable target nucleus X (initially stable) is bombarded with a projectile particle x to produce another nucleus Y (often unstable and radioactive) and a light particle or a gamma photon y. Following the discovery of neutrons (in 1932), the trans-uranium elements and artificial radioisotopes were produced with neutron projectiles in reactions such as (n,γ), (n,p), (n,α) or multi-stage processes like $X(n,\gamma)Y(n,\gamma)Z$.

Today, activation by neutron irradiation in nuclear reactors is a common practice and a veritable money spinner worldwide, except in Nigeria.

Nigeria is an oil producing nation with an extensive use of radioisotopes in the vast oil fields. From oil well logging operations upstream with AmBe neutron sources, Cs-137, Co-60 γ-sources at the exploration stage to Non Destructive Testing (NDT) of oil pipelines with thousands of Ir-192, Cs-137, Co-60 γ-sources and hundreds of level gauges with Cs-137 sources at the downstream sector, thousands of radioisotopes are being imported to Nigeria from South Africa and Europe with millions of dollars in foreign exchange annually. Many other radioisotopes are imported for use in the health and agricultural sectors of the economy. For instance, the Nuclear Medicine Department, UCH, Ibadan imports Iodine-131 ($T_{1/2}$ ~ 8 days) at least twice a month at a cost of over 6,500 Euros (N1.3m) to treat an average of 50 patients per annum for thyroid cancer.

The only nuclear reactor in Nigeria today is at the Centre for Energy Research and Training (CERT) in ABU, Zaria. Named the Nigeria Research Reactor-1(NIRR-1), its main features are presented in table 2 (Jonah and Balogun 2005). It is specifically designed for use in neutron activation analysis (NAA) and limited radioisotope production for teaching and research. I must inform this august audience that in a research reactor, the main purpose is to utilize the neutrons produced in the core as opposed to a power reactor in which the ultimate goal is to use the heat produced to generate electricity. I have visited NIRR-I and I have also had the opportunity of sponsorship by the McArthur Foundation (2006-2007) to visit a similar facility, the iThemba LABS, Cape Town, South Africa. The scopes of activities at both centres are as different as the states of the roads leading to them. Although detailed inventory of nuclear facilities in a country is not commonplace information, I know that South Africa has more than enough capabilities to meet the radioisotope needs of the whole of Africa and beyond. Either as a private investment or a national project, acquisition of a nuclear reactor for commercial production of radioisotopes is no doubt capital intensive, but what can be more capital intensive than lawmakers gulping over N339bn in four years (The Guardian, 19 June 2011)?

Table 2: Information on Nigeria Research Reactor-1(NIRR-1)

Reactor type	**Tank-in-pool**
Nominal thermal power	31 kW
Neutron flux (thermal, max.)	1.02 x 10^{12} neutrons/cm^2.s
Coolant and moderator	Light water
Reflector	Metallic beryllium
Fuel type	U-Al alloy >90% enrichment
Number of control rods	1
Control rod material	Cd
Neutron irradiation channels	5 inner and 5 outer
Cd ratio of Au	2.12 ± 0.02 (inner)
Thermal-epithermal flux ratio	19.2 ± 0.5 (inner)
Neutron temperature	333.7 K

Nuclear Power Reactor

In an attempt to produce trans-uranium elements through neutron irradiation, Enrico Fermi (in 1934) exposed uranium to low-energy neutrons and observed the production of a variety of new elements. Otto Hahn and F. Strassman (in 1938) showed by chemical separation that these products were elements with Z from 35 to 65, indicating that uranium (Z = 92) must have split or undergone a fission reaction of the form:

$$n + U \rightarrow U^* \rightarrow f_1 + f_2 + 2(3)n \qquad (1)$$

The unique thing about nuclear fission is the 2 or 3 neutrons released, which can be thermalized to cause more fissions and sustain the fission reaction. The three nuclei which can be fissioned by thermal neutrons are U-235, U-233 and Pu-239 with only U-235 occurring as 0.7% isotope of natural uranium. The other two can be obtained in breeder reactions with Th-232 and U-238 (99.3% natural U), respectively. The fission fragments f_1 and f_2 ($Z_1 \neq Z_2$) with masses randomly distributed between A = 65 and A = 170 with two peaks at 95 and 137, are highly radioactive isotopes. Professor B. Alabi of Mechanical Engineering Department, UI, in his inaugural lecture of 29 May 2001 suggested: "Perhaps any seemingly random process has its own characteristic signature (a distinctive imprint)". As a physicist, the distribution of the fission fragments is one of the many phenomena which have taught me that in nature, no event is exactly random but determined to fit some collective pattern. The collective pattern for fission products is the bimodal distribution in figure 8.

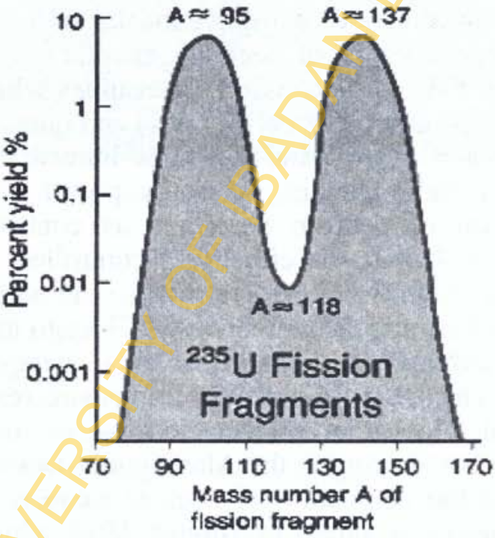

Fig. 8. Radioactive fission fragments.

It was known immediately from its kinematics that, each fission reaction results in a mass deficit $\Delta m = (M_U - m_{f1} - m_{f2} - m_n)$ which is about 0.23 amu. Albert Einstein had established from his revolutionary special theory of relativity in 1905 that, mass and energy are the same entity in different forms. He related mass m and energy E by what is certainly the best-known equation in physics: $E = mc^2$ where c is the speed of light (3×10^{10} m/s). It is quite easy to calculate that about 3.4×10^{-11} J of energy is released at each fission point. The energy derivable from 1g of U-235 which contains about 2.5×10^{21} such fission points is therefore about 1.02×10^{11} J. A power level of about 1 megawatt of heat is therefore derivable from a daily consumption of 1 g (365 g in a year) of pure U-235. This is equal to the energy derivable from about 100 kg of oil, 2,000 kg of coal or 21,000 kg of TNT (an explosive). I must, be quick to point out, however, that 100% pure U-235 is practically impossible to obtain and that only about 80% of the energy released in a fission process is carried away by the fission fragments as kinetic energy which is quickly dissipated to heat up the immediate environment.

Neutron effective multiplication factor k_{eff}, which is the ratio of the number of second generation neutrons to the number in the first generation, determines whether the chain reaction will be sub-critical ($k_{eff} < 1$) and quenches with time, over-critical ($k_{eff} > 1$) and explodes immediately or critical ($k_{eff} = 1$) and maintains a steady power level. With the introduction of neutron absorbers as control rods in the fission fuel, k_{eff} can be effectively controlled. The first self-sustaining chain fission reaction ($k_{eff} = 1$) was demonstrated by Enrico Fermi at the University of Chicago in 1942.

The military significance of this energy was quickly realized. The US government's immediate reaction was the successful Manhattan project, leading to the first atomic bomb ($k_{eff} > 1$) testing in the Alamogordo Desert (US) in July 1945, and the detonation of nuclear weapons at Hiroshima and Nagasaki in Japan in August 1945 which resulted in estimated 200,000 deaths and over 150,000 injuries. This is not talking about the people who suffered delayed effects such as cancer and genetic effects that manifested many years after (Wanebo et al. 1968). The typical devastating mushroom cloud that accompanies a nuclear bomb explosion is shown in figure 9. Proliferation of nuclear arsenals and their testing has continued to dictate the trend in world politics till today.

Fig. 9. The devastating mushroom cloud accompanying a nuclear bomb explosion.

From the point of view of the above catastrophic application of nuclear power, the scientific community has absolutely no business developing the technology. An objective analysis of its 68-year history however, will prove that the gains of peaceful applications of nuclear fission have more than compensated for the initial costs. Nuclear power reactors use the enormous heat from fission to produce pressurized steam, which turns the turbine in the same way as plants fuelled by coal and natural gas. As at 2006, there were 448 nuclear reactors in 32 countries providing 16% of the world's electricity (Settle 2009), with 68 under construction. This means that Nigeria has at least 13 countries to overtake within the next nine years if its Vision 20 2020 is anything to reckon with! The distribution worldwide according to IAEA (2006) is presented in table 3.

Table 3: Nuclear Power Reactors in the World (IAEA, 2006)

[illegible]	[illegible]	[illegible]		[illegible]	
		Number	Electricity net output MWe	Number	Electricity net output MWe
1	Argentina	2	935	1	692
2	Armenia	1	375		
3	Belgium	7	5,926		
4	Brazil	2	1,884	1	1,245
5	Bulgaria	2	1,906	2	1,906
6	Canada	18	12,569		
7	China	13	10,048	27	27,230
8	Taiwan	6	4,980	2	2,600
9	Czech Republic	6	3,722		
10	Finland	4	2,716	1	1,600
11	France	58	63,130	1	1,600
12	Germany	17	20,490		
13	Hungary	4	1,889		
14	India	20	4,391	5	3,564
15	Iran	-	-	1	915
16	Japan	54	46,823	2	2,650
17	Korea, Republic	21	18,665	5	5,560
18	Mexico	2	1,300		
19	Netherlands	1	487		
20	Pakistan	2	425	1	300
21	Romania	2	1,300		
22	Russian Federation	32	22,693	11	9,153
23	Slovakian Republic	4	1,792	2	782
24	Slovenia	1	666		
25	South Africa	2	1,800		
26	Spain	8	7,514		
27	Sweden	10	9,303		
28	Switzerland	5	3,238		
29	Taiwan	6	4,980	2	2,600
30	Ukraine	15	13,107	2	1,900
31	United Kingdom	19	10,137		
32	USA	104	100,747	1	1,165
	Total	448		67	

Source: IAEA (2006)

France produces about 80% of her electricity (63,130 MWe) from nuclear fuel. A recent study by an inter-disciplinary group in Massachusetts Institute of Technology (MIT 2009) postulates a global growth scenario that by mid-century, there would be between 1000 and 1500 reactors of 1000 MWe capacity on the average, worldwide. We will recall that the world criticized Japan with 54 power reactors (57,000 MWe) early this year, for having too many power reactors in their seismically fragile small islands. I wonder what the world should do to Nigeria with zero power reactor, for having too few in a seismically stable continent!

Right from cradle, man has been in constant search for energy because human life and development in all facets are tightly hinged on abundant energy supply. The modern man depends on electrical energy for virtually everything, the generation of which, according to Michael Faraday (in 1831), relies on basic energy inputs like falling water, heat energy from burning coal, or natural gas, to spin a turbine. Electricity (60 kWe) was first generated in Nigeria in 1896 in Lagos using thermal energy from coal. It is indeed unfortunate that almost 120 years after, Nigeria has not been able to generate and maintain 4,000 MWe for a population of about 140 million. For the laboratories to have electricity for the greater part of the day and the students to continue to cook their beans with their hot plates, Great UI requires about 2.5 MWe while Ajaokuta Steel Complex alone would require about 250 MWe if fully operational.

Mr. Vice-Chancellor Sir, at an average of 2 kWe per household and with 100% transmission efficiency, the current power level in Nigeria is about the requirement of 2,000 households, with all the factories, laboratories and offices shut down. We can now see why the electricity generating set dealers will continue to thrive. In the same continent, South Africa with a population of about 50 million generates close to 40,000 MWe with at least 2,000 MWe from nuclear fission. This translates to about 800 MWe per million. If we go by this standard, our national power requirement is about 112,000 MWe, against the current level of 4,000 MWe! In my humble opinion, all the social and economic problems facing Nigeria are traceable to the gross inadequacy of power supply. For the dead industries to come alive and new ones to start springing up, for the street lights to glow again and for you and I to watch our favourite TV programmes at home without the pollution from the fumes and noise of the generators, Nigeria needs at least 30,000 MWe of electricity.

Incidentally, this is the target of the Federal Government by the magic year 2020, which is just 9 years away (Adesanmi 2010). With the perennial fall in water levels, the incessant vandalization of the gas pipelines and strikes by coal workers, exploring the nuclear fuel option becomes inevitable in the new plan. One is quite happy and hopeful that the government has declared its intention to generate 20% of the planned energy level from nuclear power reactors. This might mean six power reactors, each of 1000 MWe. Public acceptance of these power reactors is crucial and will be determined by Nigerians being able to distinguish between the myth and the truth about atomic energy, the objective of this lecture. The Nigerian Atomic Energy Commission (NAEC) has indeed been established with distinguished scientists on its board.

From mining of natural uranium, conversion/enrichment, all through to fabrication of the uranium fuel and containment structure, to external cooling facility and radioactive waste treatment, and final disposal as shown in figure 10, the uranium cycle in a nuclear power reactor involves quite a formidable technology and a great deal of commitment. As a physicist, I will be insincere to trivialize the enormity of the level of commitment required, especially if one bears in mind the fact that the Nigerian nation has not had much to show for the 4.6 billion dollars or 750 trillion Naira (The Guardian, 28 August, 2011) spent in the last thirty years on the Ajaokuta Steel Complex. But adequate power is a sine qua non for any economy and hence, the political will is inevitable.

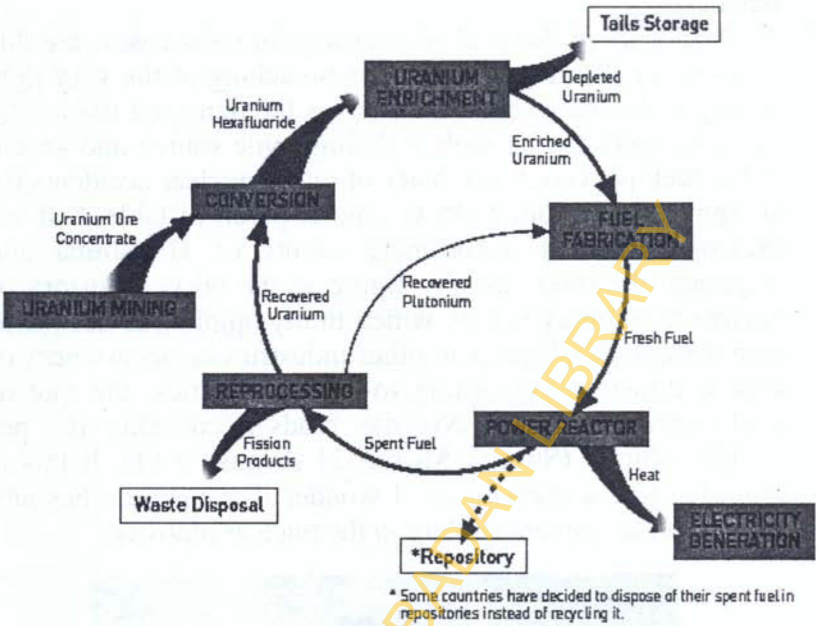

Fig. 10. Nuclear fuel cycle.

Nuclear Safety and Radiation Protection

There are a number of myths based on inaccurate information concerning nuclear safety and radiation protection around a nuclear facility like the power reactor. For a world that woke up to know atomic energy through the killing of over 195,000 people and maiming of another 161,000 with the "little boy" and the "fat man" in 1945, any level of trepidation against the application of that energy should be understood. This lecture will however, not be complete if it fails to present the facts about safety in the nuclear industry. The two types of risk in the industry are (1) the possibility of an accident that can result in acute radiation exposure within a short time and (2) the possibility of chronic exposure to low level dose over a long time with the associated risk of cancer and genetic effects. The first is the cause of the casualty figures and the reason for the public view of nuclear technology as dreadful.

The second is probabilistic, and data are often masked by other causes.

Accidents in the nuclear industry, in most cases, are due to abuse, negligence or deliberate breaching of the very tight safety mechanisms. Figure 11 shows the damaged tissue of a radiation worker who stole a radiographic source and kept it in his back pocket. A summary of major nuclear accidents for all applications from 1945 to date is given in table 4. If we exclude the most unfortunate events of Hiroshima and Nagasaki, the total casualty figure in the 66-year history of nuclear technology is 139, which in my opinion, is not worse than the casualty figures in other industries or occurrences of natural disasters. According to FRSC statistics, the rate of road crash fatalities on Nigerian roads is currently 161 per 10,000 vehicles (Sunday Mirror, 21 August 2011). If this is projected to the annual rate, I wonder if a Nigerian has any just reason to condemn safety in the nuclear industry.

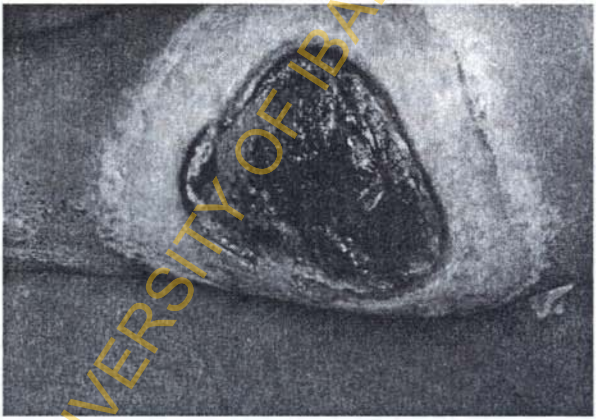

Fig. 11. Damaged tissue due to acute radiation exposure.

Tale 4: Summary Fatal Nuclear Accidents, 1945-2007

Date	Location	Type of accident/event	Fatality	Injuries	Source
06 Aug 1945	Hiroshima, Japan	Combat use of NW	130,000	86,000	* NW
09 Aug 1945	Nagasaki, Japan	Combat use of NW	65,000	75,000	* NW
04 Jul 1961	K-19 Submarine, North Atlantic	Naval reactor accident	8	31	
21 Mar 1962 - Aug 1962	Mexico City, Mexico	Lost radiography source	4	1	Co-60
24 May 1968	K-27 Submarine, Barets Sea	Naval reactor accident	9	83	
1974 - 1976	Columbus, Ohio, USA	Radiotherapy accident	10	88	Co-60
1980	Houston, Texas, USA	Radiotherapy accident	7	?	Y-90
05 Oct 1982	Baku Azerbaijan, USSR	Lost source	5	13	Cs-137
19 Mar 1984	Casablanca, Morocco	Lost radiography source	8	3	Ir-192
10 Aug 1985	K-431 Submarine, USSR	Reactor accident during refueling	10	49	
26 Apr 1986 - 06 May 1986	Chernobyl, Ukraine, USSR	Steam explosion and fire in power reactor	31	238	
12 Sep 1987 - 29 Sep 1987	Goiania, Brazil	Accidental dispersal of lost radiotherapy source	5	20	Cs-137
10 Dec 1990 - 20 Dec 1990	Saragossa, Spain	Radiotherapy accident	18	9	
22 Aug 1996 - 27 Sep 1996	San Jose, Costa Rica	Radiotherapy accident	7	81	Co-60
Aug 2000 - 24 Mar 2001	Panama City, Panama	Radiotherapy accident	17	11	
			139		

*NW = Nuclear Weapon (Fatality excluded from total)

Source: Johnston (2008)

The fear of a nuclear power reactor is often exaggerated. A popular myth is that a nuclear power reactor can explode anytime like the atomic bomb. This is as incorrect as discouraging cooking of *moinmoin* just because there has been an accident with frying *akara*, which is a different beans product. The truth is that, it is not possible for a reactor to explode like an atomic bomb because the latter contains very special materials, in special grades and in very particular configurations, none of which are present in a nuclear reactor. With about 105 power reactors (100,747 MWe) in the US, no single fatality has been recorded to date. The incident of the Three Mile Island in 1979 was easily curtailed without any loss of human life. The annual radiation burden to the citizenry has not been affected to any significant level. According to NCRPM, No. 92 (1988) and NCRPM, 95 (1989), only 0.005% of the average American's yearly radiation dose comes from nuclear power; 100 times less than what is absorbed from coal, 200 times less than the dose from cosmic-rays received in a 3 hr flight, and about the same as gamma radiation dose due to ^{40}K absorbed from eating 1 banana per year.

From 1942 to date, at least 50 power reactors have been successfully decommissioned worldwide and their environments restored for normal use. I have had the opportunity of an IAEA fellowship to work on an old reactor site in Southern California, USA. The maximum concentration of Cs -137 measured was 0.43 Bq/kg (Farai and Dahl 1999) which is the same order of concentration as Th-232 (0.395 Bq/kg) measured in front of Government House, Agodi (Farai and Jibiri 2000a; Farai and Jibiri 2000b) and hundreds of times less than the radioactivity in building blocks around an old tin mine in Jos (Ademola and Farai 2006).

As presented in table 4, the most destructive nuclear accident to date is the Chernobyl (Ukraine, USSR) power reactor explosion of April 1986 with 31 fatalities and an estimated 350 injuries. In a response to the fears expressed about contamination of milk products imported into Nigeria after the accident, I conducted a gamma assay of milk samples in the Nigerian markets and found no case of contamination (Farai 1993). Subsequent reviews of the accident (IAEA 1992) have revealed that the accident was due mainly to lapses in the design of the reactor. The nuclear reactor core contains essentially the fuel with a moderator to thermalize neutron energy from MeV to about 0.025 eV. It also has control rods to maintain criticality (k = 1). The heat produced must be effectively removed to avoid build-up and possible melt down of the containment structure. There are at least six common designs of power reactors, depending mainly on the characteristics of the materials used at the different stages. The Chernobyl reactor was a Light Water Graphite-Moderated Reactor (RBMK) type. Several design characteristics of the RBMK reactor—in particular, the control rod design and a positive void coefficient, were unsafe, which is why the RBMK reactor was never built outside the Soviet Union. A lot of lapses were also traced to the technicians on duty on the day of the accident. After the accident, major modifications have been made to those still operating.

The recent incident at Fukushima, Japan, was caused by a devastating natural phenomenon. The great East Japan Earthquake of 11 March 2011 (M = 9), generated a series of large tsunami waves that struck the east coast of Japan with more than 14,000 lives lost. Although the waves (14 m high) overwhelmed the defences of TEPCO`s Fukushima Daiichi power reactor, one of the 54 power reactors in Japan, and caused a number of explosions and fires at the reactor buildings, to date (IAEA Interim Report, June 2011), no health effects have been reported in any person as a result of radiation exposure from the nuclear accident. I am not sure there is any other human assemblage that can withstand the great force behind the tsunami as much as the reactors in Japan did. This fact underscores the robustness of nuclear structures in general.

Natural Environmental Radioactivity

The earth is made up of over 100 different elements, most of which have decayed to stability since creation. A few however, have radioactive half-lives comparable with the age of the earth (4.54×10^9 years) and therefore still exist in small amounts in the earth, soil and rocks till today. Prominent among these primordial radioactive elements are ^{238}U, ^{232}Th and ^{40}K (0.012% natural K) which are found in varying amounts in different environments. Both ^{238}U and ^{232}Th have long decay series with many members (^{226}Ra, ^{222}Rn, ^{214}Bi etc.), all of which are radioactive. Radiations emitted mainly by these primordial elements and members of their decay chains present within 15 – 30 cm topsoil, reach the earth surface. The installation and operation of a nuclear facility in an environment require that the natural radiation level of the area be accurately known for a reliable future impact assessment. A major lesson from the radioactive fallout of the Chernobyl accident, the large-scale environmental contamination from the radiological accident in Goiania, Brazil (in 1987) and the Koko waste dump in Nigeria (in 1988), was the urgent need to have baseline data in Nigeria for environmental radioactivity against which pollution measurements could be assessed. This problem attracted my interest and I have for the past twenty five years devoted a lot of energy to it.

I must at this point acknowledge the tutelage I received from a pioneer radiation physicist in Nigeria, in person of Dr. A.O. Sanni, who supervised my M.Sc and PhD programmes. He launched me into the world of research in environmental radioactivity. His interest must have arisen from several research visits he and his research colleagues made between 1969 and 1985 to tin mine sites in the Jos plateau (Sanni 1970; Nwosu and Sanni 1973; Sanni 1977; Babalola 1981; Oresegun and Babalola 1985). In a particular study, Sanni et al. (1985) revealed that air concentrations of insoluble Th (3.5×10^{-7} μC/cm^3) and U (1.3×10^{-6} μC/cm^3) in the neighbourhood of the mines were four times greater than the ICRP maximum permissible values. Dr. Sanni also led the team of scientists that assessed the Koko waste dump, and I can remember his concern about the matter. The Bible talks of God giving different gifts to different people. God gave Dr. Sanni the gift of painstaking thoroughness, which I lack by nature. Although he bequeathed almost all his library to me, I felt completely abandoned by his early exit from academics to answer divine call to full-time pastoral work immediately after my PhD. I however, realized later that he had equipped me with all I needed to proceed from where he stopped. I received the painful news of Dr. Sanni's death about 3 weeks ago while I was preparing for this lecture. May his soul rest in peace.

I started work on environmental studies with ^{222}Rn, a naturally occurring radioactive gas ($T_{1/2}$ = 3.8days) from the radioactive decay of ^{226}Ra in the U series. According to NCRP Report 93 (1988), ^{222}Rn accounts for 55% of human exposure to radiation, followed by the rest of the natural sources (26%), medical X-rays (11%), nuclear medicine (4%), consumer products (3%) and others like weapon tests, nuclear fuel, etc. (1%). It is therefore an unfortunate irony that people campaign against nuclear technology with all its very stringent measures that keep radiation exposure at very safe levels, only for them to return to their poorly ventilated homes to be exposed to the high risk of cancer due to build-up of natural Rn.

Radon gas can diffuse from utility water, foundation, cracks or blocks in walls and build up in the dwelling space, especially with inadequate ventilation. We stay indoors for about 80% of the time. The health risk due to Rn arises from the carcinogenic alpha and beta doses delivered by its decay products (Po-218 and Po- 214) directly to the lung tissue when inhaled and to the walls of the stomach when ingested. With an estimate of 21,000 annual lung cancer deaths, inhaled radon is the leading cause of lung cancer among non-smokers in the US (USEPA 2003). The dose-response relation seems to be linear without evidence of a threshold, meaning that the lung cancer risk increases proportionally with increasing radon exposure. The agency recommends specific actions to be taken if indoor radon level is 4 pCi/L (0.15 Bq/L) or more.

The use of groundwater in homes is the major channel of transportation of Rn into the dwelling space. Because of its high solubility in water, Rn is easily transferred from the rock matrix of the aquifer into groundwater. Radon in utility water presents two pathways for human exposure; direct ingestion, and inhalation of the transferred fraction in air. Data were quite sparse on baseline levels of Rn concentrations in underground water systems in different geological settings in Nigeria, yet the use of groundwater through boreholes and natural springs had remained very high. Farai and Sanni (1992) developed a low-cost but sensitive gamma counting technique for the measurement of Rn in groundwater for the first time in Nigeria. A number of representative boreholes and natural springs, including Ikogosi warm spring in SW Nigeria and Kerang natural spring in the Jos plateau, were sampled. As shown in table 5, Rn concentrations ranged between 1.7 ± 0.1 Bq/L in basalt rocks, and 161.6 ± 2.4 Bq/L in the younger granitic rocks, with 50% of the groundwater systems sampled exceeding the maximum limit of 11.1 Bq/L recommended by the USEPA for Rn in utility water (USEPA 1991). A maximum limit of 50 Bq/L which would reduce the risk of the stochastic effects to about 3 cases in 10,000 was recommended for Nigeria (Farai 1990). This limit was exceeded in about 30% of the groundwater systems sampled.

The WHO has established the International Radon Project in which over 20 countries (excluding Nigeria) have formed a network of partners to identify and promote programmes that reduce the health impact of radon. The first meeting of the Project was held in Geneva in January 2005 to develop a strategy for dealing with this important health issue. The key objectives of the project include, creating a global database (including maps) of residential radon exposure, and estimating the global health impact of exposure to radon in homes and so allow resources to be allocated effectively to mitigate the health impact of radon. I was fortunate to win a grant of N400,000 in the 2006 edition of the Senate Research Grants of this University, with which our team acquired an

Electret Rn detection unit for the first indoor radon monitoring project in Nigeria. We published our first paper (Ojo et al. 2011) two months ago, which established the applicability of our technique and set the stage for a much wider scope of indoor radon survey in Nigeria. Ventilation was observed as key factor in radon build-up in homes.

Table 5: Radon Concentrations in Groundwater from three Rock Types

Rock Type	Location	Mean Radon Concentration (Bq/L)
Old Granites	Ibadan 1	50.3 ± 9.0
	Ibadan 2	14.8 ± 1.4
	Ibadan 3	10.0 ± 1.1
	Ibadan 4	9.9 ± 0.3
	Awe - Oyo	3.1 ± 0.3
	Ile-Ife	6.0 ± 0.6
	Ilesha	5.5 ± 0.3
	Ijare – Akure	8.6 ± 1.2
	Ikogosi (Warm Spring)	4.7 ± 0.8
Sedimentary	Abeokuta	33.1 ± 3.3
	Ago-Iwoye	3.8 ± 0.3
	Olodo	12.5 ± 1.1
Young Granites	Jos 1	80.6 ± 1.2
	Jos 2	61.7 ± 0.9
	Jos 3	161.6 ± 2.4
	Jos 4	25.8 ± 0.4
	Bukuru	46.2 ± 0.8
	Barki Ladi	7.1 ± 0.9
	Kerang	1.7 ± 0.1

Apart from Rn bearing utility water, concrete blocks used for construction of residential buildings contain naturally occurring ^{238}U, ^{232}Th and ^{40}K, with activity levels that depend on locations from where the raw materials (cement, sand and water) have been sourced. This will eventually lead to radiation exposure and health burden on the occupants. In order to examine the total exposure caused by the three radio-nuclides U, Th and K, their radioactivity concentrations are combined in terms of radium equivalent, which is defined as:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \qquad (2)$$

where C_{Ra}, C_{Th} and C_K are the respective radioactivity concentrations.

A radium equivalent of 370 Bq/kg in building material which has been estimated to produce an exposure of 1.5 mSv/year to the inhabitants (UNSCEAR 1982) has been set as the safe limit for homes. Unlike in most parts of the world, little was known about the radioactivity level in construction materials in Nigeria. With our efforts (Farai and Ademola 2001; Farai and Ademola 2004; Ademola and Farai 2005), some modest achievements have been made for SW Nigeria. Values of radium equivalent in concrete block samples from major cities in this region are presented in table 6 with Oyo town having the least (81 ± 18 Bq/kg) and Abeokuta having the highest value of 145 ± 141 Bq/kg. The large error limits indicate the large variations in values for most cities. Values as high as 446 Bq/kg which exceed the safe limit were obtained for some samples in Abeokuta. The results of gamma spectroscopic analysis of radioactivity in major brands of cement in Nigeria (Farai and Ejeh 2006) are presented in figure 12. All the values are within the acceptable limit. Sediments used as the sand component of building concrete were also investigated. A total of 207 sediment samples collected from 20 surface water dams in Ekiti, Ondo, Osun, Oyo and Ogun States were assayed for their radioactivity levels. The mean annual indoor effective dose rates for a 4 m x 5 m x 2.8 m room built with such sediments were found to range from 0.43 to 1.01 mSv, which were essentially within the internationally recommended maximum limit of 1 mSv (Farai and Isinkaye 2009a; Farai and Isinkaye 2009b).

Table 6: Radium Equivalent in Building Blocks in Some Cities SW Nigeria

City	No of Samples	Range of Ra_{eq} (Bq/kg)	Mean Ra_{eq} (Bq/kg)
Abeokuta	21	90 – 446	145 ± 141
Akure	17	78 – 169	110 ± 23
Ado-Ekiti	10	67 – 168	96 ± 30
Ibadan	32	51 – 176	92 ± 29
Agege	15	81 – 225	104 ± 60
Osogbo	12	56 – 134	85 ± 28
Oyo	10	63 – 127	81 ± 18
Ogbomoso	13	81 – 113	91 ± 11

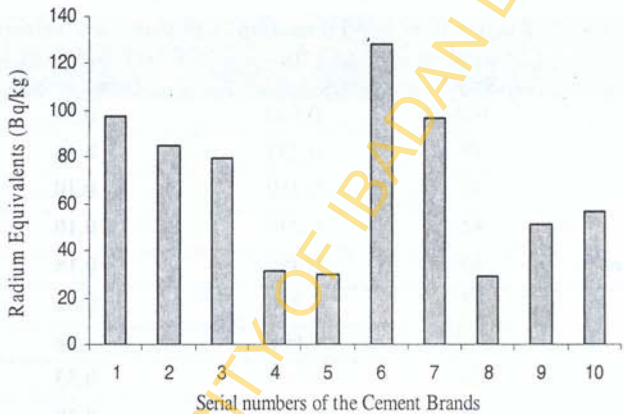

Fig. 12. Radium equivalents in brands of cement in Nigeria.

We spend about 5 hours per day outdoors, which is enough time to incur undesirable outdoor radiation dose. The formidable economic and logistics problem of transporting soil samples from all parts of the country to our low-level gamma counting laboratory in Ibadan for sample to sample assay, was realized. We had to develop a rapid, low-cost but reliable *in-situ* gamma counting system using a model that had been successfully applied in Hungary (Zombori et al. 1983).

Mr. Vice-Chancellor Sir, the success of that effort is that today, we have baseline data for environmental radioactivity in 18 cities in different geological settings in Nigeria (Farai and Jibiri 1998; Farai and Jibiri 2000a; Farai and Jibiri 2000b; Jibiri and Farai 2005). A summary of mean annual effective dose equivalents in the cities are given in table 7 with ten of the cities exceeding the 70 $\mu Sv.y^{-1}$ world average. Jos (284 µSv/y) had the highest, followed by Abeokuta (273 µSv/y). Other works (Jibiri et al. 1999; Obed et al. 2005; Farai and Vincent 2006) have consistently shown Abeokuta as the area of highest natural radioactivity in SW Nigeria.

Table 7: Effective Dose Equivalents in 18 Nigerian Cities

City	Effective Dose Equivalent ($\mu Sv.y^{-1}$)*	Population ($x10^6$)	Collective Effective Dose Equivalent x 10^2 (man. $Sv.y^{-1}$)
Enugu	103	0.520	**0.54**
Onitsha	49	0.287	**0.14**
Owerri	32	0.319	**0.10**
Umuahia	42	0.239	**0.10**
P. Harcourt	40	0.455	**0.18**
Warri	37	0.336	**0.12**
Jos	284	0.696	**1.98**
Bauchi	138	0.382	**0.53**
Gombe	88	0.317	**0.28**
Kaduna	112	0.711	**0.08**
Kano	103	1.525	**1.57**
Makurdi	59	0.253	**0.15**
Benin	57	0.873	**0.50**
Lagos	50	6.357	**3.17**
Akure	130	0.354	**0.46**
Abeokuta	273	0.419	**1.14**
Ibadan	96	1.367	**1.31**
Ilorin	**75**	**0.640**	**0.48**

* World average value = 70 $\mu Sv.y^{-1}$

The significance of outdoor radiation exposure due to natural radioactivity in soil and the potential risk for causing epidemiological problems had not received adequate attention in Nigeria. Based on data from the nationwide surveys, Obed et al. (2005), and Farai et al. (2006) investigated a possible relationship between reported cancer incidence and outdoor radiation dose in the 18 cities. A correlation analysis between the total reported R cancer incidence per year and the expected E cancer cases per year from soil radioactivity, based on the linear no-threshold (LNT) model, showed (with $R = 0.7$) that:

$$R = 9.124E + 155.13 \qquad (3)$$

It was observed that cancer cases attributable to radiation exposure due to soil radioactivity is low, constituting only between 1.3% and 9.2% of the total reported cases.

The Niger Delta region has been subjected to intensive oil exploration and mining activities in the last four decades. Many of these activities, such as radiography of oil pipelines and installations, oil well logging, level gauges, tracer techniques, among others, involve the use of radioactive materials of assorted strengths, half-lives and physical forms. Before the NNRA came into existence in the year 2001, there was virtually no control in Nigeria on the use of nuclear materials. Many radioactive sources could have gone into wrong hands and indeed, a few losses were reported. The extent of the dispersal of such possible lost sources and unsafe waste disposal cannot be known. With the dense network of rivers and creeks in this region, the aquatic environment is the most likely recipient of any such failure in containment of radioactive materials.

This problem received our attention and the result of our efforts is that today we have baseline data for this region on natural radioactivity in aquatic species (Farai and Oni 2003), in soils from different communities (Arogunjo et al. 2004), and in waste dump sites (Farai et al. 2007). In a study (Oni and Farai 2006), the effective dose equivalent due to consumption of aquatic animals by dwellers in the different communities in the area was investigated. A dose equivalent of 0.169 $mSvy^{-1}$ was obtained which is well below the recommended limit of 1 mSv/y (NRPB 1991). No artificial radioisotope was detected in any of the media investigated showing that containment measures put in place by the oil companies are quite effective.

Non-Ionizing Radiations

Apart from the particulate α and β radiations, radiations that we encounter in the environment are electromagnetic waves, which travel in the form of varying electric and magnetic components and hence, require no material medium to propagate. They travel in vacuum with the velocity of light. They differ from one another only in frequency (or wavelength) and techniques of production. It is not all of them that can ionize. The complete electromagnetic spectrum is shown in figure 13 with the ionizing group demarcated from the non-ionizing group.

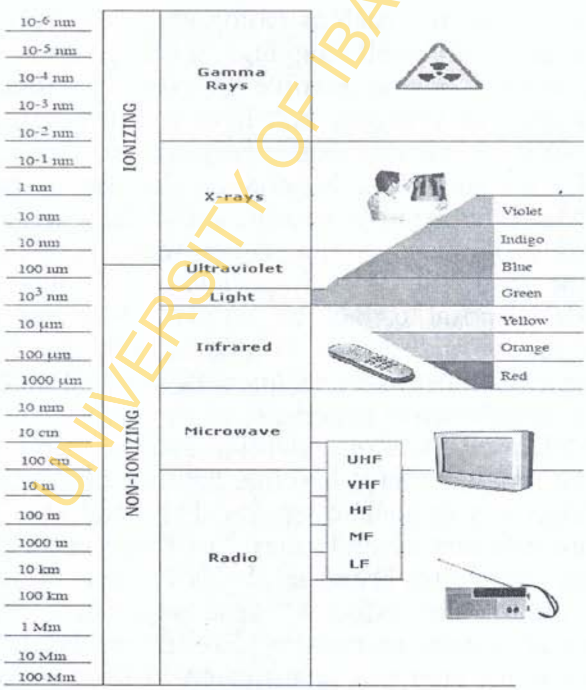

Fig. 13. The electromagnetic spectrum.

The Global System of Mobile Communication (GSM)

The GSM consists of base station antennas which communicate with the mobile station (hand-set) via radiofrequency (900 MHz and 1800 MHz) transmission and reception. Other systems operating in this range of frequencies include TV, FM and AM broadcasting, Paging, WiFi, Bluetooth, etc. Introduced in Nigeria in 1999, the GSM has experienced phenomenal annual growth of about 37% (Wills and Daniels 2003). In order to have effective coverage, the operators have installed heavy clusters of base station antennas in all the major cities across the country. These are mounted on masts of varying heights, which are located in both commercial and residential areas of each city.

Concerns have been raised over possible detrimental health effects such as cancer, due to radiofrequency (RF) radiation from the GSM base stations. The anxieties have been heightened by some alarmist publications by some of our scientists in the dailies (e.g. *The Nation*, 25 January 2011). There are speculations that there are some non-thermal health stochastic effects at the low power densities of the GSM operations. The claims include sleep disturbances, dizziness, heart palpitations, headache, blurry sight, swelling, nausea, a burning skin, vibrations, and electrical currents in the body, pressure on the breast, cramps, high blood pressure, and general debility. In one particular case, it was reported that a canary bird did not sing anymore and lost its feathers after being at 50 m from a base station! Of course the fears would be carried to ridiculous extents in a superstition laden society like ours. Some say they experience strange sensations in different parts and organs of their bodies after using the GSM phones. Some people believe the demons can phone their intending victims with the GSM. One would drop dead if calls from certain numbers were answered. Many would bluntly oppose GSM masts being erected near their houses. These are myths. We need to know the truth.

One fundamental problem is that people do not know that there are different radiation types and energies. All crawling animals are not snakes! The energy of a photon in GSM signals is either 4 μeV (900 MHz) or 8 μeV (1800 MHz). These energies are million orders of magnitude less than the minimum radiation energy of about 16 eV that can ionize water molecules and lead to the health effects discussed earlier in this lecture. It is however, a fact that the interaction of time varying electric fields as RF signals in GSM communication, micro-wave heating or radio and TV communication with human tissue can result in the formation of oscillating electric dipoles as well as ionic current, both of which may result in heat production in the tissue. It is only at very high intensities as we have in the microwave oven chamber that the heat can result in significant body temperature increase with associated health effects. The current intensity limits recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP 1998) and backed by the WHO are 4.5 W/m^2 for GSM 900 Hz, and 9.0 W/m^2 for GSM 1800 Hz. These levels have been adopted by the Nigerian Communication Commission (NCC). Well documented studies by the Australian Radiation Protection Nuclear Safety Agency have shown that the recommended levels are thousands of times below the levels where significant heating can occur.

In order to determine compliance with protection guidelines, our research team has investigated (ongoing research projects) the power levels of RF radiation to which the people living or spending some time within 200 m radius of over 400 GSM base stations in Ibadan and Lagos cities, may be exposed. The maximum value obtained is 199.5 mW/m^2, which is hundreds of times less than the ICNIRP and NCC maximum. It may interest us to know that after reflection and absorption by the atmosphere, the intensity of solar radiation bathing us on the earth's surface is on average, 198 W/m^2 (Wallace and Hobbs 1977). This is thousands of times more than the power density that any base station or even a radio station can emit. Going by the hues and cries on GSM safety, we should all have been killed by sun rays.

In the case of the hand-set, with the user's head usually within the near-field of the transmitted signal, radiation energy absorbed by the head is quantified in terms of Specific Absorption Rate (SAR). For most national regulatory authorities, the maximum permissible SAR is $2^{W}/_{kg}$ which is also thousands of times less than the level where any significant thermal effect can occur. We have so far not come across any hand-set that exceeds this regulatory limit.

Mr. Vice-Chancellor Sir, the current position of the WHO on these various claims is based on a recent review by 31 scientists from 14 countries in France (WHO/IARC 2011). The conclusion from the assessment is to classify RF electro-magnetic radiation as possibly carcinogenic under class 2E, which means that there is limited evidence in humans, and less sufficient in experimental animals to show the link between RF exposure and cancer. In my humble opinion, the various myths only show that humanity has not yet woken up from the 66-year old nightmare of Hiroshima and Nagasaki atomic bombing.

Conclusion

Mr. Vice-Chancellor Sir, all I am trying to say is that nuclear technology is a highly profitable human invention and worth investing on by a nation. The myths about its safety should be objectively weighed against existing facts. Indoor exposure to natural radioactivity is far higher than what can be incurred from a safe application of nuclear technology. Nigeria should embark on the development of nuclear technology and Nigerians should accept it. This is the trend worldwide. My colleagues and I in Ibadan have acquired a fair size of data on environmental radioactivity to prepare the grounds for nuclear technology in Nigeria.

Acknowledgements

I must start by expressing my appreciation of the solid foundation and love my siblings and I received from our late parents, Pa David and Mama Comfort Farai. Although mere peasants and without any formal education, they could see far

beyond their time and space. They taught us self reliance and a great sense of responsibility. At age 20, my senior brother and my mentor, Mr. Oladeji Farai (1945-1990), was matured and responsible enough not only to leave home but to take me at age 11 with him to train. He trained me and trained himself to become one of the foremost computer scientists in Nigeria and an accomplished academic at Obafemi Awolowo University, Ile-Ife. Nothing would have given me greater joy than to have brother Deji seated here physically today. I thank God for the lives of his wife, Mrs. Ebun Farai, his children—Ifedayo, Ayodeji and Olajumoke, and my junior brother, Alaba Farai, who are present here today. I thank God also for the lives of my cousins on both sides, Engr. Ropo Alabi, Mr. Busayo Alabi, Engr. Folorunso Oluwajana, Mr. Biodun Alabi, Mr. Ola Aiyesoro and Mr. Benson Aiyesoro. Together, we have weathered the storm. I thank my in-laws, particularly Mrs. Bola Onimole, an ever pleasant and loving lady, and Engr. Akin Akintewe, who is more of a friend to me than an in-law. I relish sharing frequent deep intellectual discussions with him.

Time was when there were 'camps' and daily clashes in Physics Department, UI. The atmosphere was so tense and unpredictable that some people suggested that the Director of the Zoological Garden should look for cages to keep some of us. Mr. Vice-Chancellor Sir, without any intention to be immodest, I wish to inform you that today, Physics Department is one of the most peaceful Departments in the University. The magic is the love and the confidence that I have enjoyed as the HOD from every one of my colleagues—from the doyen of the family, Professor E.O. Oladiran, to the youngest in the Department. Time will not permit me to mention everybody by name but I must acknowledge the special love and support I enjoy from my former PhD students; Drs. Nnamdi Jibiri, Janet Ademola, Rachel Obed and Tunde Oni, who are now my colleagues in the Department. I must also express gratitude for the support I have enjoyed from Dr. F.O. Ogundare, my Deputy HOD (Academics) and Dr. E.O. Awe, my Deputy HOD (Admin.).

In the larger university community, I am like an electron in a three-energy state atom. I have friends and mentors in the higher state who always descend to my level to express love and affection to me. I have friends in the lower energy state of the atom who are always inspired to share warmth with me. I also have friends who are always in the same energy state with me. There is always something personal between me and each one of them. Some of them help me to solve problems that I would not have if they were not my friends. I will mention just a few representatives here—Professors S.O. Fagade (Uncle Fag), Biodun Falusi, Bode Lucas, Femi Osofisan, Ayo Oluleye, Idowu Olayinka, Segun Taiwo, Charles Uwakwe, Alex Odaibo; Drs. Olu Aleru, John Dongo, Yemi Adejuwon, Segun Sotiloye, and Mr. Funso Yoloye (Uncle Yo). I thank you all for putting some spices into my life in UI.

I have carried out fruitful interdisciplinary, collaborative research activities with Professors O. Osibanjo, O. Ekundayo, R. Oderinde, and P.C. Onianwa, from which I have gained much professional experience. I am grateful.

I belong to a few associations and groups, members of which have shown me love and affection over the years. In this regard, I wish to thank the Chaplaincy, the entire congregation and in particular, members of the Men's League, Chapel of the Resurrection for my spiritual wellbeing. I also thank members of the Tennis Group, Senior Staff Club, UI, the IJSO (Nigeria) Family, Alafia Estate Residents Association, and Oyemekun Old Students' Association for their love and good wishes. I thank also, all my little friends at the Father Christmas grotto who I look forward to meeting every year.

I am a very happy man because the good Lord has given me a home of my dream where love and affection radiate. This is one of the rare occasions that I must put my feelings into words. First to my wife, darling and friend, Adenike, I say thank you for always being by my side and giving all the support. To Omotayo OreOluwa (*Mr.T!*), you have always been for me a pleasant proof of your name. To Taiwo Itunu (*Tai-Tai*), you have remained my true comforter and the reason for my joy, and to my pet and baby, Oluwatosin Idowu (*Nobless*), you remain the apple of my eye!

To God Almighty, my creator and my guardian all through thick and thin, I say:

Great is Thy faithfulness, O God my Father... Morning by morning new mercies I see, All I have needed Thy hand hath provided, Great is Thy faithfulness Lord, unto me!

The Vice-Chancellor Sir, ladies and gentlemen, I thank you all for your attention.

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BIODATA OF
PROFESSOR IDOWU PETER FARAI

Idowu Peter Farai was born on 5 September 1954 to the family of Pa David and Mama Comfort Farai in Ijare, Ondo State. He started his elementary education at St. Mary's Primary School, Ijare, in January 1960 and completed it at St. Stephen Anglican Primary School, Ikare, in December 1968, after a few breaks and relocations. He had his secondary education at Oyemekun Grammar School, Akure, between January 1969 and June 1973, among the first set of Nigerian students to finish secondary school education in June. He worked as an examination officer in the West African Examination Council (WAEC) office, Ibadan between November 1973 and September 1975.

He proceeded to the University of Nigeria, Nsukka, in September 1975 for his tertiary education and studied Physics as a Federal Government scholar. He was the President, National Association of Physics Students. While in Nsukka, Idowu was not inhibited by any tribal barrier to the extent that he won elections to several Students' Union positions and by the time he graduated with B.Sc. (Hons) in June 1979, he was communicating fluently in Igbo language.

He started the NYSC year at the Federal School of Arts and Science, Mubi (in the former Gongola State), and finished at the Polytechnic, Ibadan, where he later taught for two years. He joined the University of Ibadan as a Graduate Assistant in the Physics Department in October 1982, and immediately embarked on his postgraduate studies, specializing in Radiation and Health Physics. He completed the M.Sc programme in June 1984 and the PhD degree in January 1990, by which time he was a Lecturer Grade II in the Department. He rose through the ranks to become a Professor in October 2006.

Professor Farai is a member of several national and international associations including the Nigerian Institute of Physics (NIP), the Third World Academy of Science

(TWAS), Science Association of Nigeria, the Nigerian Association of Medical Physicists (NAMP), the Nigerian Scientific Committee for the International Junior Science Olympiad (IJSO), and the International Conference on Radionuclide Metrology (ICRM). He is a member of the Board of the Nigerian Institute of Radiation Protection and Research. He was at various times the Sub-Dean (Physical) and Sub-Dean (Postgraduate), Faculty of Science. He is currently the Head of Department of Physics.

A proficient teacher respected by all generations of his students, Professor Farai has successfully supervised seven PhD and numerous M.Sc. research projects. Many of these former research students are now senior academics in the Department and various other institutions in Nigeria and abroad. He has published about 50 articles in reputable local and international journals in his area of research. He is an external examiner at both undergraduate and postgraduate levels to many universities in Nigeria, South Africa and Ghana. He was for many years the national coordinator of Nigeria/IAEA projects on Radioactive Waste Management and Radiation Protection. He is a consultant to the Federal Government of Nigeria on Radiation Protection and to the IAEA on curriculum development for Postgraduate Studies in Radiation Protection.

Professor Farai is happily married to Mrs. Adenike Farai of the Publishing House, University of Ibadan. The marriage is blessed with three lovely children.